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Whiting of the Irish Sea and the Clyde

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Part I: Whiting in the Irish Sea

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INTRODUCTION

THE whiting, *Merlangius merlangus* L., is a ubiquitous species found throughout the coastal waters of the British Isles and in the deeper waters of the continental shelf. Because it does not normally achieve the commercial importance of cod and haddock, the species has, until recently, aroused relatively little interest from the standpoint of fishery management, despite its large numbers. Nevertheless, the whiting has always been important to certain European fishing interests, and detailed biological investigations are therefore being undertaken to determine the distribution and fundamental biology of the species in relation to the general post-war expansion of fishing activity.

The greater part of this work has been concerned with the North Sea whiting (Ellis and Jones 1956; Gambell 1958, 1959, 1962; Messtorff 1959), and very little published information relates to the Irish Sea whiting which is important to the United Kingdom and Ireland and some continental countries. This is shown in Table 1 by the proportion of whiting in the total catch of demersal species from ICES Statistical Region VIIA by England, Ireland and Northern Ireland during the years 1956–60.

Table 1. *The proportion of whiting in the total demersal catch from Region VIIA by England and Wales, the Republic of Ireland, and Northern Ireland* 1956–60 (*gutted weight, cwt*)

	England and Wales			Ireland (East coast)			Northern Ireland		
	Total demersal	Whiting	Whiting as % of total	Total demersal	Whiting	Whiting as % of total	Total demersal	Whiting	Whiting as % of total
1956	253,961	59,603	23·5	78,904	40,076	50·8	70,065	48,443	69·1
1957	291,765	64,397	22·1	99,405	49,196	49·5	81,852	60,016	73·3
1958	235,691	55,663	23·6	111,287	69,957	62·9	103,067	76,356	74·1
1959	187,185	56,374	30·1	108,543	66,570	61·3	111,327	94,073	84·5
1960	194,929	75,668	38·8	94,880	54,661	57·6	44,234	27,824	62·9

Earlier work on these stocks by Scott (1913, 1915), Bowers (1954) and Gokhale (1957) has been concerned with the spawning cycle and the rate of growth. More recently information relating to the overall distribution of whiting has become available through the English market sampling system, and in this paper these data are collated and analysed to show the wider aspects of the structure of the populations.

THE DATA AVAILABLE

STATISTICS of total catch (and fishing effort, where this is given) have been taken from the annual reports and statistical tables of the Governments of Great Britain, the Republic of Ireland and Northern Ireland (see Table 5). In recent years more detailed information is available, the catch and effort figures for English and Welsh vessels being subdivided according to statistical rectangles and class of vessel (over 40 feet). These have been abstracted since 1955 to show the seasonal distribution of whiting off the west coast but the main body of information has been collected since 1957, when length-frequency records of whiting landed at Fleetwood, Milford Haven and the Northern Irish ports were started. As the complexity of the populations became clear this sampling was extended to Conway (North Wales) in 1960, and to Whitehaven (Cumberland) in 1962.

Otolith samples for age-determination have been collected at Northern Irish ports since 1957, but this sampling was only started at English ports in 1962, although additional information is available from research vessel cruises.

Further research work has been carried out by the Republic of Ireland since 1959. The published data generally confirm and amplify English records (see Hillis 1960, 1962).

THE SEASONAL DISTRIBUTION OF WHITING IN THE IRISH SEA

WHITING may be found in different parts of the Irish Sea throughout the year, but it is characteristic of the species that at certain times of the year the fish aggregate to form dense local concentrations which provide the basis for seasonal fisheries. These are shown in the

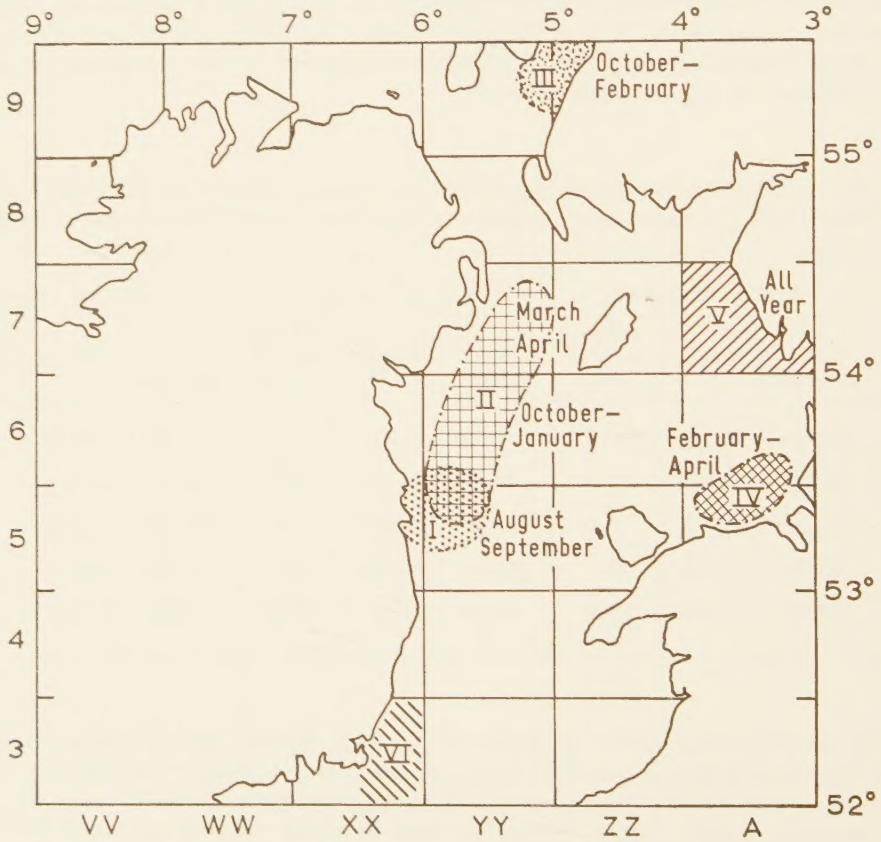

Fig. 1. *Sketch map of the principal seasonal whiting fisheries in the Irish Sea.*

Table 2. *The contribution of catches from the seasonal fisheries to the total Irish Sea whiting catch,* 1958–60 (*cwt*)

	Areas I and II				IV	V	VI		
Months	England	N. Ireland	Rep. Ireland	Total	England	England	England	Elsewhere	Total
Jan.-Mar. 1958	2,896	16,501	8,134	27,531	3,290	1,699	3,113		
Apr.-June 1958	2,328	4,991	3,564	10,883	5,659	2,295	2,984		
July-Sept. 1958	1,467	957	7,855	10,279	588	10,257	933		
Oct.-Dec. 1958	9,516	53,613	43,504	106,633	2,665	1,383	507		
1958 Total				155,326	12,202	15,634	7,537	11,277	201,976
(%)				(76·9)	(6·1)	(7·7)	(3·7)	(5·6)	
Jan.-Mar. 1959	1,301	20,195	8,875	30,371	2,765	2,241	1,976		
Apr.-June 1959	1,001	2,426	2,079	5,506	2,472	8,484	1,850		
July-Sept. 1959	811	11,936	18,781	31,528	606	9,940	753		
Oct.-Dec. 1959	2,096	59,514	29,735	91,345	1,625	14,320	534		
1959 Total				158,750	7,468	34,985	5,113	10,701	217,017
(%)				(73·2)	(3·4)	(16·1)	(2·4)	(4·9)	
Jan.-Mar. 1960	897	7,272	10,571	18,740	4,558	14,714	794		
Apr.-June 1960	184	701	3,001	3,886	5,689	10,715	3,289		
July-Sept. 1960	1,425	746	13,623	15,794	886	8,290	399		
Oct.-Dec. 1960	4,118	19,105	27,266	50,489	2,494	11,901	817		
1960 Total				88,909	13,627	45,620	5,299	4,698	158,153
(%)				(56·2)	(8·6)	(28·8)	(3·4)	(3·0)	

chart in Figure 1, and the contribution of each fishery to the total catch of whiting from Region VIIA is given in Table 2, excluding continental catches which are not known. The progress of these fisheries can be described briefly.

During August and September a fishery develops off Dublin in the vicinity of Rockabill and Lambay Island (Area I in Figure 1). This population is fished by vessels from the Republic of Ireland, which are joined by a proportion of the Northern Irish fleet of fly-seiners and trawlers as the herring and *Nephrops* seasons decline. During the final quarter of the year the fishery extends northward, forming the main County Down fishery (Area II) which is exploited by the Irish fleets and a small number of English, Scottish and continental vessels.

The fishing season declines during the first quarter of the following year and ends in April at the approaches to the northern entrance to the Irish Sea. The Irish fleets then divert their attention to *Nephrops* and later herring, but whiting continue to be taken in small numbers throughout the summer, although their total is very small in comparison to the catch during the main season (see Table 2).

This County Down fishery is very intensive, contributing as it does 70% of the whiting landed from the Irish Sea by the United Kingdom and the Republic of Ireland. In the Solway Firth also the recorded abundance of whiting is greatest in the last three months of the year, but commercial fishing in this area contributes very little to the total catch of whiting from Region VIIA and is included under 'elsewhere' in Table 2. A third winter fishery, which occurs in the Firth of Clyde (Area III), is described by Gambell (1960, 1962, and in Part III of this publication).

During early February the 'Conway' fishery develops off North Wales (Area IV). This is fished by the English and Welsh trawlers and by seiners from Fleetwood, in addition to continental vessels and larger Irish boats which in recent years have landed at Amlwch and Holyhead. The catch by England and Wales from this fishery amounts to some 5% of the total from Region VIIA.

A similar fishery occurs in March and April off the south-east tip of Ireland (Area VI). English landings from the area represent 3% of the total for Region VIIA, but because these whiting stocks show a greater affinity with the whiting populations of Regions VIIF and VIIG this fraction is excluded from further considerations relating to Region VIIA.

East of the Isle of Man a whiting fishery persists throughout the year off Whitehaven (Area V). English landings from this region have recently increased from 25% of English landings in 1959 to some 50% in 1961; in 1960, the last year for which full international statistics are available, these landings represented 28·8% of the total catch from Region VIIA.

The various other foreign (including Irish) landings of whiting direct to English ports may amount to a further 3% of the total for the region, but because of uncertainty of origin of the fish these are not included in the figure quoted.

THE LENGTH-COMPOSITION OF THE IRISH SEA WHITING POPULATIONS

THE COUNTY DOWN POPULATION

Representative percentage length-frequency distributions taken from commercial catches and landings at Northern Irish ports during the winter season are shown in Figure 2. These fisheries use 50–55 mm cod-ends, which means that all fish larger than 20 cm are represented in the catch, though a minimum size limit of 25 cm causes some rejection before the catch is landed. Figure 2(i) is a sample of the total catch measured aboard a commercial seiner in February 1957; it shows a mode at 25 cm. Figure 2(ii) is the length-frequency of the *landed* catch by Northern Irish seiners in the last quarter of 1957, when the landings had the highest mean length since sampling began. The mean length-frequency distribution of the County Down landings in the same quarter of 1958–61 is shown in Figure 2(iii). Figure 2(i) includes the undersized fish which are rejected at sea. In some seasons these may be very numerous, and the modes of the landed catches shown in Figures 2(ii) and 2(iii) may therefore be slightly higher than those of the *actual* catch.

There is very little shift in these modes during a season, but year-to-year variation is considerable. However, the larger whiting tend to be found in deeper water and, though the total catch of all boats may have a composite distribution similar to those shown, there is clear indication of regional size segregation within the general area. This is apparent in the split mode of the November 1959 distribution in Figure 2(iv); Hillis, sampling an Irish commercial vessel at the same time, recorded only the upper mode (Hillis 1960).

During the remainder of the year the Northern Irish vessels concentrate on other species, and so no representative samples are available. Research vessel sampling and commercial catch sampling by Hillis during this period have shown that the distinctive mode of the seasonal fishery disappears, and whiting may be taken throughout the length range until the late summer when a new year-class, previously identified and followed with small-meshed gear, becomes large enough to appear in commercial catches.

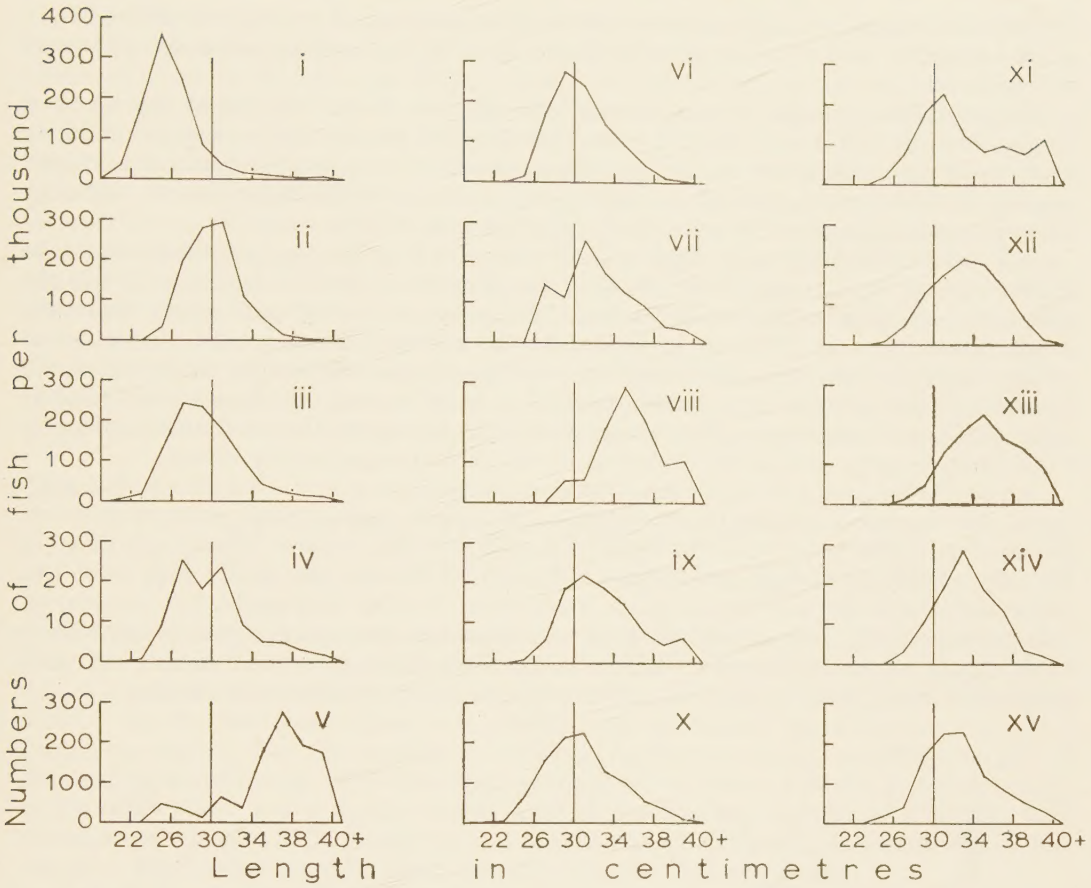

Fig. 2. *The percentage length-frequency distribution of samples of whiting from various parts of the Irish Sea.* (i) *Total catch, Northern Irish seiner; February* 1957. (ii) *Landed catch, Northern Irish seiners; October–December* 1957. (iii) *Landed catch, Northern Irish seiners; mean, October–December* 1958–61. (iv) *Landed catch, Northern Irish seiners; November* 1959. (v) *Landed catch, Milford Haven trawler; Rectangle ZZ 6, April* 1957. (vi) *Landed catch, Conway; mean,* 1957–61. (vii)–(xv) *Landed catch, Fleetwood; monthly means,* 1957–61.

Even during the summer period the length-frequency of the population varies with the depth sampled. A deep-water record from a Milford Haven trawler working south-west of the Isle of Man is shown in Figure 2(v). The principal mode of this distribution lies between 35 and 40 cm, but there are minor peaks at 25 and 31 cm which probably correspond to younger age groups. The trawl used in obtaining this sample would have had a cod-end mesh of 75 mm, with a 50% retention length of 29 cm for whiting, so that fish at the lower of these two modes would not have been fully retained. However, the upper mode at 31 cm is accurately shown and indicates that in this sample these younger age groups were less well represented than the 35–40 cm fish.

WHITING POPULATIONS EAST OF THE ISLE OF MAN

The landings of Irish vessels discussed above were taken with 50–55 mm gear, whereas the distributions from English catches in Figure 2(vi)–(xv) were taken with 70 cm cod-ends. These do not retain the smaller fish found in the County Down fishery, and the presence of small fish east of the Isle of Man is therefore not recorded except in research vessel samples.

Nevertheless the gear is uniform within the English samples and any shift in modal length can be regarded as a true record, with the reservation that additional modes may exist below 26 cm.

Figure 2(vi) represents the mean length-distribution of the whiting in the Conway fishery (Area IV in Figure 1) for the years 1957–61. This population has a mode at 30 cm which is very constant from year to year. Research vessel sampling by means of a covered cod-end in 1960 showed this same distribution, no lower modes being present, although fish with a modal length of 19 cm were found in the area in 1963.

The length-distributions in Figure 2(vii)–(xv) are monthly samples taken from the English fishery in rectangles A 7 and ZZ 7 (see Figure 1). In March (Figure 2(vii)) the distribution is similar to that of the Conway fishery, but in April (Figure 2(viii)) the modal length of the more northerly population is slightly greater. Thereafter the proportion of smaller whiting in this population increases until June (Figure 2(x)), when the modal length is lowest. This is followed by a second period of increase in the modal length until October, when additional recruitment again reduces it until, by December (Figure 2(xv)), the length-distribution is again comparable with that of the forthcoming Conway fishery.

As at Conway, research vessel sampling in rectangles A 6 and A 7 has shown that additional fish having a very restricted length-composition, with a mode at approximately 20 cm, may or may not be present. Figure 3 A compares two research vessel hauls taken in the same general area (rectangles A 6 and A 7) in April 1960; in the one haul the catch was composed of small fish with a mode at 20–21 cm, while the other haul sampled the population fished commercially, with a mode at 30 cm. A similar variation can be found in the Solway Firth whiting, as seen in Figure 3 B, which compares a research vessel haul in May 1961 with commercial hauls taken in the first quarter of the year. The distinction is obvious.

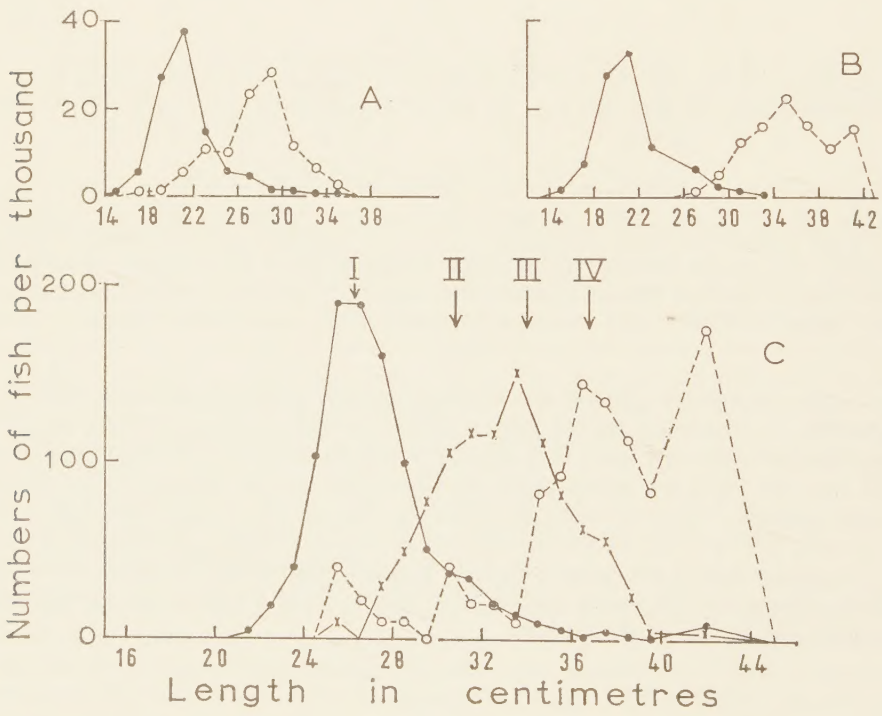

Fig. 3. *Percentage length-compositions of whiting.* A. *Two hauls by a research vessel with a covered cod-end in rectangles A 6 and A 7, April* 1960. B. *Research vessel catch with a covered cod-end, Solway Firth, May* 1961 (*solid circles*) *and the commercial landed catch from the same area in January–March* 1961 (*open circles*). C. *Comparison of the length-distributions shown in Figures* 2(i) (*solid circles*), 2(vi) (*crosses*) *and* 2(v) (*open circles and broken line*).

Two different types of length-frequency can be recognized amongst these distributions, depending upon the presence of fish with a modal length of 20–25 cm. These may occur alone anywhere in the Irish Sea (Figures 3 A and 3 B) or, later in the year, they may be large enough to become associated with older whiting and appear in commercial catches similar to those sampled in the County Down fishery (Figure 2(i)). In the second type this lower mode is not present in such dominant numbers; hence the mode of the distribution usually lies between 30 and 35 cm, as in Figures 2(vi) and 2(vii)–(xv). Figure 2(v) is thought to represent an extension of this type which may be found in deeper water where the mode of the distribution is still higher. The types shown in Figure 2(i) (the total catch of a commercial seiner in the County Down fishery in February 1957), Figure 2(vi) (represented by the landed catch from the Conway fishery in March 1957 only) and Figure 2(v) (the deep-water sample from south-west of the Isle of Man in April 1957) are compared in more detail in Figure 3 C to illustrate the differences. This illustration is re-examined below, following a discussion of the age-composition data, but it is already clear that the whiting populations demonstrate a degree of segregation by size, at least at certain times of the year.

THE AGE-COMPOSITION OF THE IRISH SEA WHITING POPULATIONS

A CONTINUOUS series of age-determinations is at present available only for the catch landed from the County Down fishery. In these a bias caused by the rejection of undersized fish causes a serious underestimate of the true proportion of I-group whiting, but with this in mind it can be seen from Figure 4 A, showing the percentage age-composition in three successive seasons, that this population is heavily dependent upon I- and II-group fish. It may also be noted that in 1957–8 the I-group whiting contributed a smaller proportion than in the other years, and it was in this season that the landings showed an unusually high modal length (Figure 2(ii)). Assuming that rejection was comparable to that of other years, this must have been caused by poor recruitment of the 1956 year-class.

Otolith samples from English commercial catches are not available for the years 1957–61, but some information can be derived from the research vessel samples shown in Figure 4 B. The Conway fishery in April 1960 contained only III- and IV-group whiting, and the lower mode of the Solway Firth distribution in May 1961 (Figure 3 B) was composed of I- and II-groups. The 'birthday' of Irish Sea whiting is taken as April 1 (Gambell and Messtorff 1964), and these ages should therefore be read as one group less for direct comparison with the age structure of the County Down stock in the previous October-March season. Thus the II-group Northern Irish fish (Figure 4 A) were born at the same time as the III-group caught 1–5 months later at Conway (Figure 4 B). Similarly the I- and II-groups of the May 1961 Solway Firth sample corresponded to O- and I-group whiting in the County Down population of the 1960–1 season.

These O-group whiting did not appear in the commercial catches in the County Down fishery because they were then six months younger and too small, but research vessel sampling has shown that these fish are about 17 cm long at that time (see Hillis 1960). By the following May, when they are I-group, they are approximately 20 cm in length.

No age-determinations are available for the 'deep-water' type of length-distribution, but the pattern can be deduced from the data available for the County Down and Conway fisheries, and the length-distributions shown in Figure 3 C. The County Down population is composed of predominantly I- and II-group whiting, whose modal lengths are still recognizable in the deep-water sample. The Conway fishery contains II-group fish with a mode close to that of the comparable age group in the County Down fishery, and with additional discontinuities representing probably III- and IV-groups. (These became III-, IV- and V-groups after April 1 of the year of sampling.) The third length-distribution is composed of III-group and older whiting. In effect these distributions represent a time series as one age group grows through the population, showing how it is found in association with different age groups as it grows older.

Fig. 4. A. *Percentage age-composition of the Northern Irish landings of whiting in the* 1957–8, 1958–9 *and* 1959–60 *seasons.* B. *Percentage age-compositions of research vessel hauls in the Conway fishery, April* 1960, *and in the Solway Firth, May* 1961. *The age groups in brackets denote corresponding age groups in each area; the formal age of the samples shown in B is one year higher, since the 'birthday' of whiting is taken as April* 1.

The area distinctions in length-distributions are supported by the age-compositions, showing that particularly the youngest fish of O- and I-groups may segregate from the older II + whiting, except in the County Down fishery, and even here indications are that the age groups are still to come extent separate.

Bowers (1954) has recorded that whiting spawn for the first time at the end of their second year of life, though a small proportion of the males may do so earlier. The County Down populations would therefore consist mainly of immature and newly maturing whiting,

whereas the lower modes of Figures 3 A and B show the segregation of immature from adult fish earlier in the year when these samples were taken.

THE DISTINCTION BETWEEN WHITING STOCKS WITHIN THE IRISH SEA

EVIDENCE FROM LENGTH- AND AGE-COMPOSITION DATA

The analysis of the length- and age-compositions of these various seasonal fisheries shows clearly the dependence of the County Down fishery upon juvenile and newly mature whiting. In view of the high yield from this fishery compared with the remainder of Region VIIA (see Table 2), it is of considerable importance to determine to what extent adjacent fisheries depend for recruitment upon survivors from the County Down fishery. To this end the available age-determinations and length-compositions have been combined with the abundance data from English motor trawlers, to give approximate estimates of the catch per unit effort of each age group in the County Down area compared with other regions of the Irish Sea. The data are arranged in Table 3 and Figure 5 to show the mean numbers of each year-class caught per 100 hours fishing during the period October 1957–December 1960.

Interpretation of these statistics is limited by the bias introduced by the selection characteristics of the gear, but some general conclusions can be drawn. The abundance of the age groups III + is fairly uniform throughout the area, but the I- and II-groups show a seasonal increase in abundance in the County Down fishery. I-group fish would be too small to be fully represented in the catches, and indices for this age group in areas outside the County Down fishery will therefore not be accurate, but the estimates for II-group fish should be reasonably reliable. These latter fish are partially represented in other areas east of the Isle of Man, but do not achieve a comparable abundance with County Down fish until the end of their third year, and it will be recalled that this is the age when all members of one year-class can be expected to have matured. These data therefore suggest that the shoaling habits and distribution of whiting change at maturity, the juveniles recruiting principally to the County Down fishery at the end of the year whilst the mature fish are more widely and uniformly distributed over the whole area. It has not been possible to test this supposition, because some immature fish are present outside the County Down area, as shown by the research vessel samples, and, conversely, the County Down population always contains its proportion of the more uniformly distributed mature stock, and hence could not be expected to be composed only of immature fish.

The indices of density of the 1958 year-class are particularly relevant to the problem of stock differentiation within the Irish Sea. Figure 5 shows that this year-class became uniformly distributed one year earlier than usual, resulting in the seasonal peak abundance of II-group whiting not reaching its usual strength in the County Down fishery at the end of 1960. The effect of this was evident in the commercial fishery and is shown by the catches and abundance of whiting in the final quarter of the years 1957–60 (Table 4). Compared with earlier years the 1960–1 County Down season was very poor both in the abundance of whiting and in the total catch, but the mean density of whiting of all ages over the whole of the Irish Sea, and of the 1958 year-class in particular, was up to average. It appears that this distribution was atypical in that the 1958 year-class failed to recruit to the County Down fishery in any numbers.

EVIDENCE FROM TAGGING EXPERIMENTS

The most conclusive evidence of the degree of mixing of the whiting stocks within the Irish Sea has come from the results of three large-scale tagging experiments carried out in the

Table 3. *The abundance of whiting (numbers per 100 hours fishing) recorded by English and Welsh motor trawlers in the Irish Sea*

	Year-class	Oct.-Dec. 1957	Jan.-Mar. 1958	Apr.-June 1958	July-Sept. 1958	Oct.-Dec. 1958	Jan.-Mar. 1959	Apr.-June 1959	July-Sept. 1959	Oct.-Dec. 1959	Jan.-Mar. 1960	Apr.-June 1960	July-Sept. 1960	Oct.-Dec. 1960
(i) County Down area	1959												1,232	6,884
	1958								475	5,328	3,074	2,219	2,889	4,294
	1957				1,212	6,579	4,081	2,197	1,470	7,500	3,419	2,438	1,994	1,203
	1956	1,340	199	1,593	3,149	11,407	4,691	2,601	1,190	4,119	1,772	1,254	718	152
	1955	11,919	8,799	8,393	4,802	6,222	1,518	986	729	2,121	803	550		
	1954	5,532	4,020	1,575	753	1,054	318	248	136					
	1953	348	355	91	128	209	34							
	Total number	19,139	13,373	11,652	10,044	25,471	10,642	6,032	4,000	19,068	9,068	6,461	6,833	12,533
(ii) Rectangles ZZ and A, 5, 6, 7, 8	1959												1,141	3,616
	1958								384	1,220	3,397	2,058	4,069	4,542
	1957				78	143	503	890	1,900	3,753	4,313	3,392	2,797	1,759
	1956	674	134	775	900	1,307	1,660	1,880	1,741	2,940	2,637	2,623	1,315	272
	1955	4,016	5,327	6,390	3,115	3,759	3,000	2,439	1,341	1,531	1,291	1,367		
	1954	1,729	2,342	1,473	643	746	1,059	804	304					
	1953	119	134	114	89	137	131							
	Total number	6,538	7,937	8,752	4,825	6,092	6,353	6,013	5,670	9,444	11,638	9,440	9,322	10,189

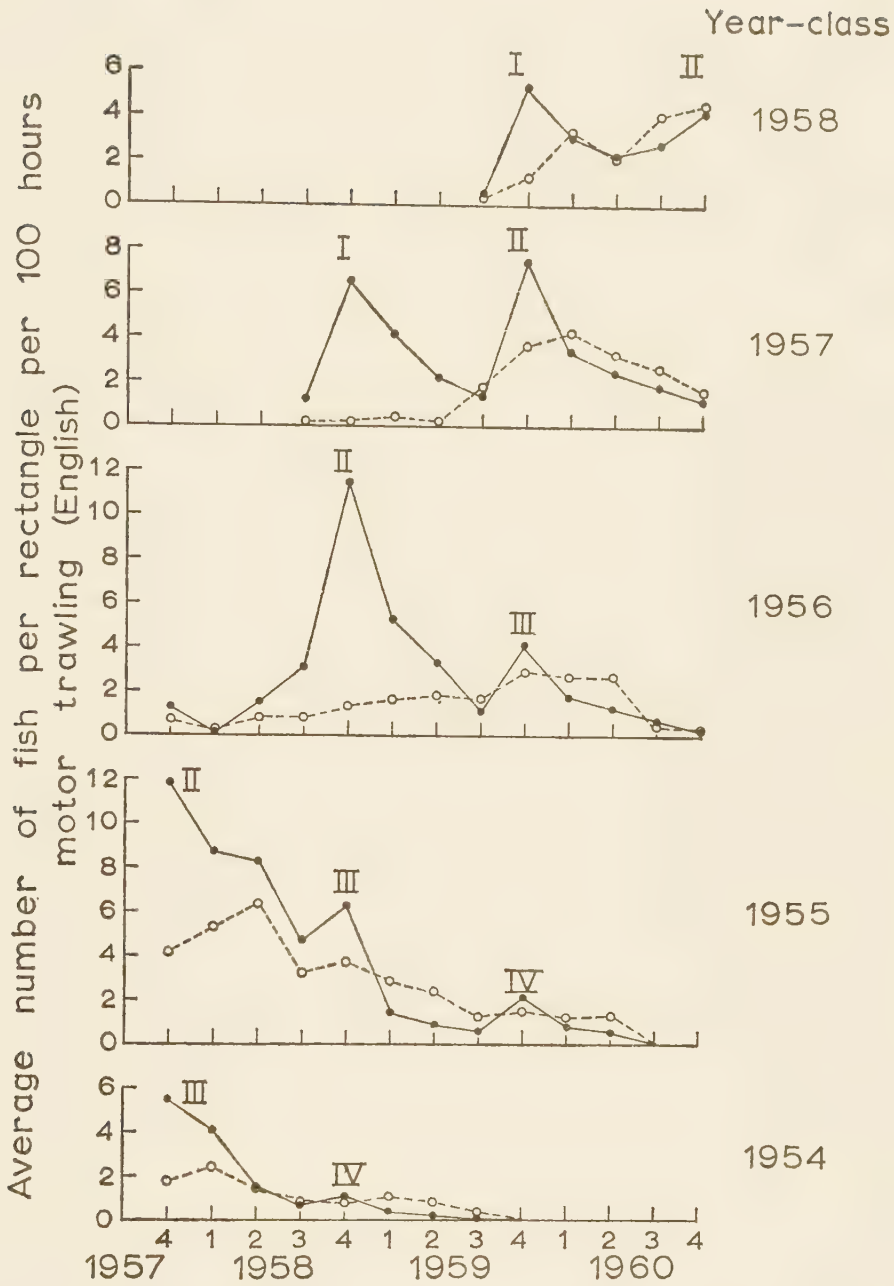

Fig. 5. *The numerical catch per* 100 *hours' fishing of successive year-classes of whiting in the County Down fishery (solid circles) and elsewhere in the Irish Sea (open circles).*

County Down area in the 1957–8 and 1958–9 seasons. These results, described in Part II of this publication, show that the seasonal decline in abundance of whiting in the County Down fishery is caused by the combined effects of intensive fishing and emigration of whiting from the area.

The chart of returns of tagged fish from outside the marking area is reproduced in Figure 6. The time of recapture is not given because this to some extent reflects the seasonal distribution of fishing effort, but the majority were caught in the spring following tagging,

Table 4. *The mean density of whiting in the County Down fishery and elsewhere in the Irish Sea during the months of October–December in* 1957–60

	1957	1958	1959	1960
Number/100 hours Whole Irish Sea	9,059	9,960	11,369	10,658
Number/100 hours County Down only	19,139	25,471	19,068	12,533
Total catch (cwt) County Down only	78,615	106,633	91,345	50,489

March–May. Fish were recaptured in three principal areas, east of the Isle of Man, off south-east Ireland and near the Firth of Clyde.

Figure 7 illustrates the results from a series of releases round the periphery of the Irish Sea during the summer months between County Down seasons. This shows the immigration of fish to the County Down fishery where they were subsequently recaptured.

The frequency distributions of the length at release of the returns from the various experiments are shown in Figure 8. Figure 8 A shows the distributions of fish liberated in the County Down area in the 1957–8 season, and it can be seen from 8 A(ii) that whilst fish recaptured east of the Isle of Man had a similar length-distribution to the tagged population (8 A(i)), the returns from greater distances (shown in 8 A(iii)) contained a higher proportion of larger fish. This difference cannot be attributed to growth, because all these returns came within one year and at much the same time in both groups.

Figure 8 B(i) shows the combined length-distribution of all comparable releases, during the summer experiments, in areas around the periphery of the Irish Sea. Figure 8 B(ii) indicates the movement of a greater proportion of smaller whiting into the County Down fishery, compared with the recaptures from elsewhere (8 B(iii)).

It is of interest that fish marked in the Conway fishery were all adult, according to the age-composition samples taken at the same time, and these moved northward to an area east of the Isle of Man (Figure 7). None were recaptured in the County Down fishery.

The general pattern of these returns shows that the various populations fished within the Irish Sea are not independent unit stocks: whiting may move considerable distances, but a greater proportion move south rather than north to the regions west of Scotland.

Other analyses of meristic characters and blood groups have not shown the existence of distinct unit stocks within the Irish Sea and it is concluded that these whiting populations represent different phases, or different parts of the same phase, of one stock of whiting which is not completely distinguishable from adjacent stocks outside the Irish Sea.

THE GROWTH OF IRISH SEA WHITING

Both Bowers (1954) and Hillis (1960) have recognized the sexual dimorphism in the growth of Irish Sea whiting, and this feature is well documented for all other whiting stocks that have been studied (Saemundsson 1925, Desbrosses 1948, Messtorff 1959 and Gambell 1960). The sexes have not been distinguished in the age-distributions collected from the Northern Irish commercial samples, and therefore only a compound age/length key is available; this has been applied to the data to give the catch per unit effort of each age group. The percentage of the total catch per unit effort of an age group within each length group can then be plotted on arithmetic probability paper to give an estimate of the 50% length of each age group. This is more accurate than taking the mean length of a sample, especially if the sample is small. An example of this technique is shown in Figure 9.

These 50% lengths are plotted in Figure 10, together with results from studies by Fulton (1901), Thomson (1904) and Bowers (1954). The length of I-group fish has been slightly overestimated, owing to the bias introduced into the original samples by rejection aboard the commercial boats. For the remainder the results are in agreement, showing that the growth of Irish Sea whiting is comparable with that of North Sea whiting (Ellis and Jones

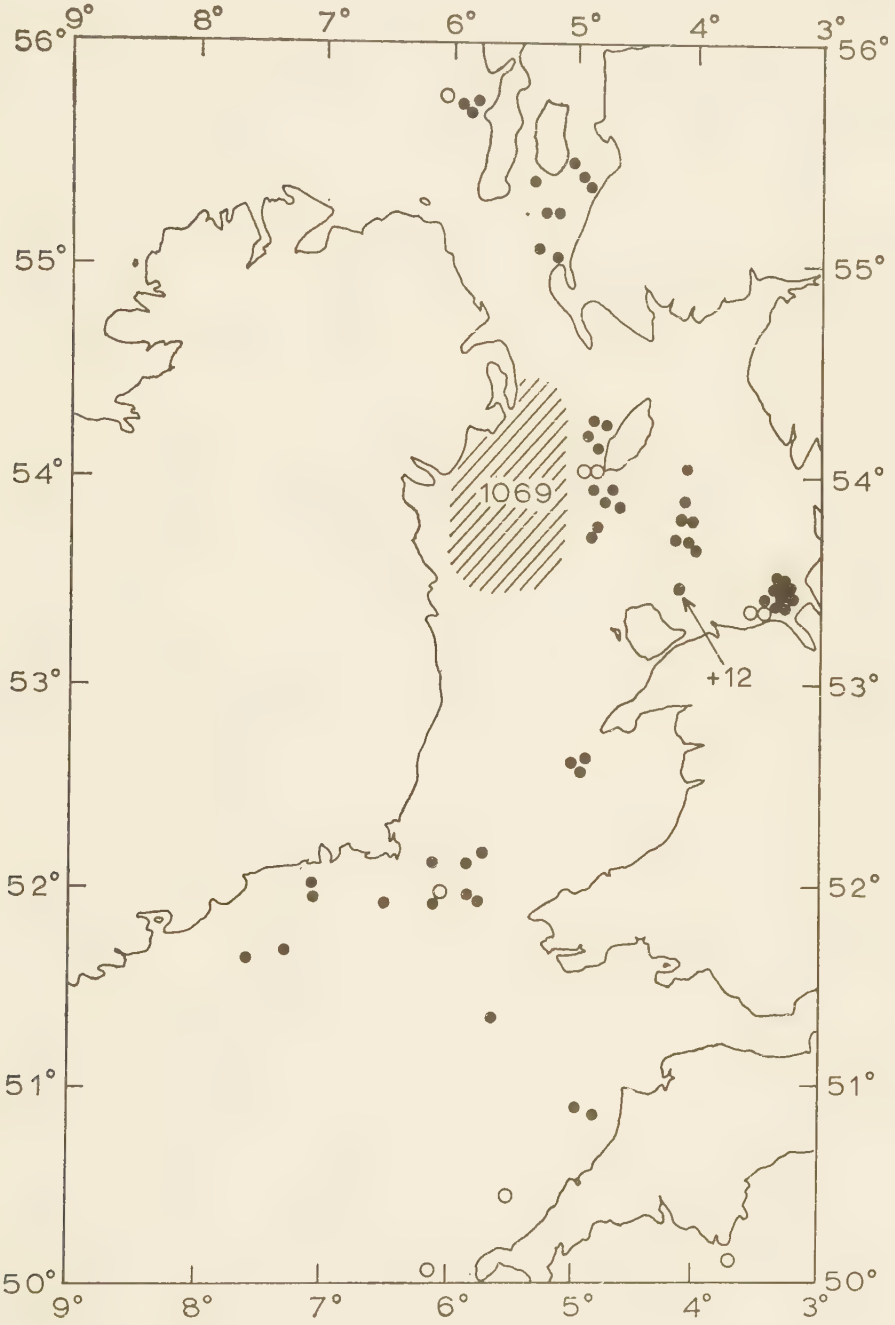

Fig. 6. *The geographical distribution of tagged whiting returned from outside the marking area, following releases in the County Down fishery in* 1957–8 (*solid circles*) *and* 1958–9 (*open circles*). (*Each point represents one fish unless otherwise indicated.*)

1956, Messtorff 1959), but less than that of Clyde whiting (Gambell 1960, and Part III of this publication).

The samples upon which the present estimates are based came from the one locality, the County Down fishery, but more recently Hillis has sampled whiting of particular year-classes over a greater variety of depths and has reached slightly different results (Hillis 1963). He concludes that although Irish Sea whiting of the younger age groups O, I and II are smaller than Clyde whiting of comparable ages, this difference is not apparent in fish of III-group and older. This confirms that a degree of bias may have been introduced into the estimates of mean length for age by taking data from a limited area, although the present data are weighted by the commercial catches of different length groups whereas Hillis'

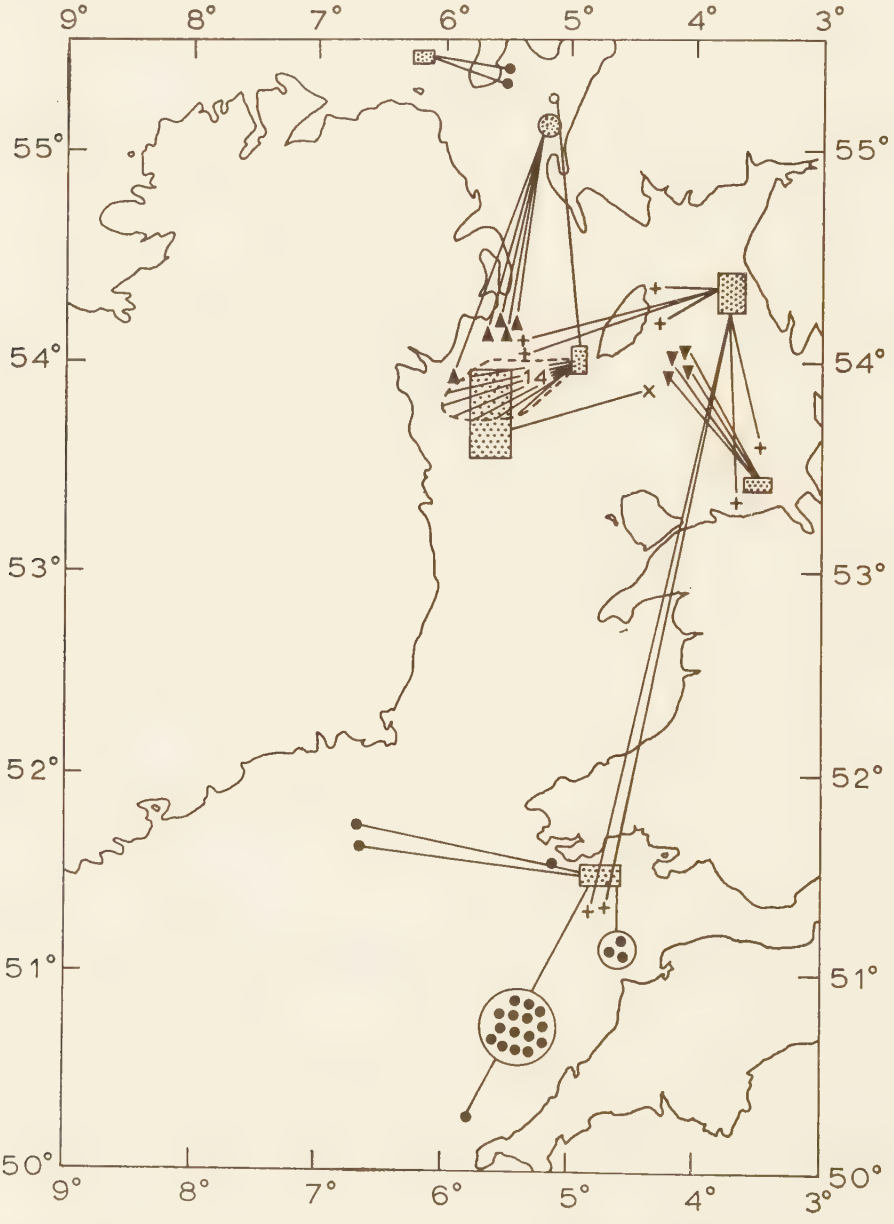

Fig. 7. *Chart of recaptures from whiting marked during the summer months at various stations in the Irish Sea.*

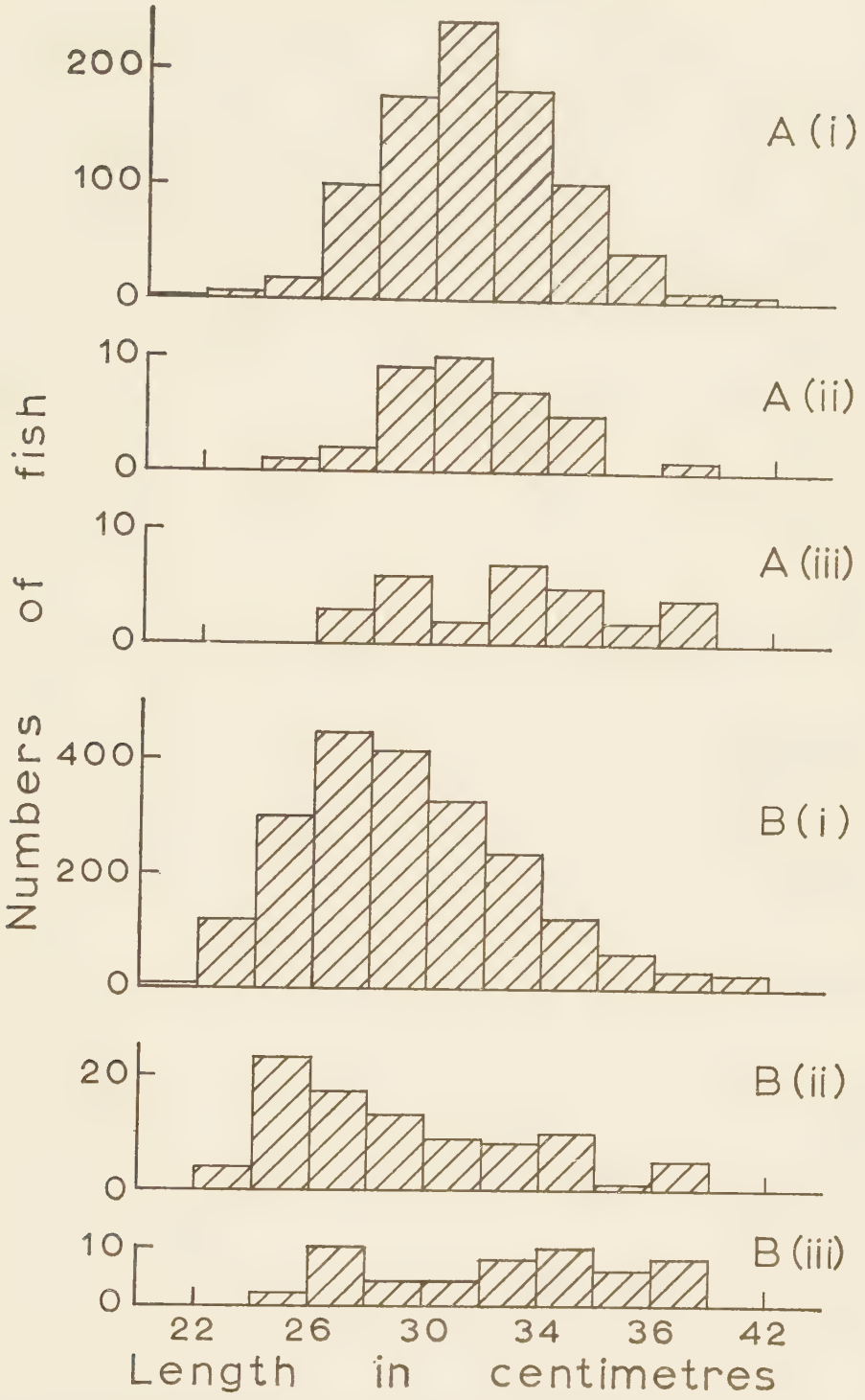

Fig. 8. A. *Frequency distributions of length at release of whiting liberated in the County Down area in* 1957 -8*:* (i) *whiting recaptured in the County Down locality;* (ii) *whiting recaptured east of the Isle of Man;* (iii) *whiting recaptured elsewhere.* B. *Frequency distributions of length at release of whiting liberated around the periphery of the Irish Sea between County Down seasons:* (i) *all releases;* (ii) *whiting recaptured in the County Down fishery;* (iii) *whiting recaptured elsewhere.*

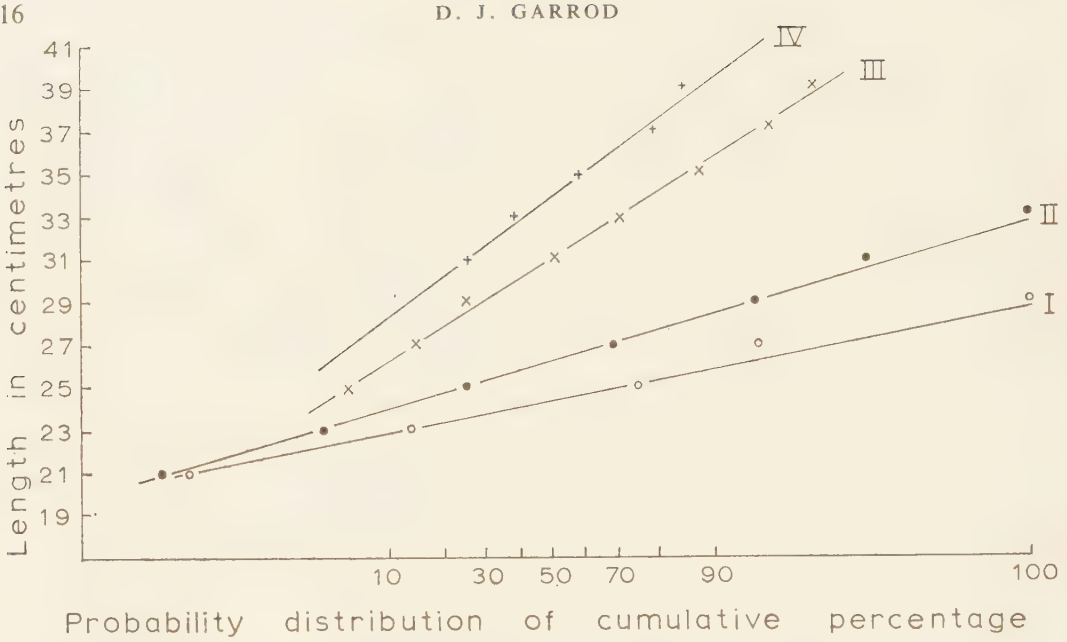

Fig. 9. *Length-distribution of each age group of whiting in the Northern Irish commercial samples for October–December* 1958, *plotted on probability paper.*

results are means as sampled. However, this bias is also reflected by Bowers' data which include mean lengths of older age groups not represented in the County Down samples. These fish were trawled in somewhat deeper water (40–45 fm), indicating again the movement of the older fish and the faster-growing fish of all ages, which causes a degree of bias in estimates of growth rate based on samples from one particular locality. Bowers also gives data to show that the seasonal growth of whiting is more or less complete by October. The relevance of this to the overall structure of these whiting populations is discussed below.

DISCUSSION OF THE DISTRIBUTION OF WHITING WITHIN THE IRISH SEA

THE various data described above permit some conclusions to be reached on the general distribution of whiting within the Irish Sea, which can best be described by following the life history of a hypothetical year-class.

After the adoption of the demersal habit the juveniles remain in much the same area for their first and possibly second years of life. One of the principal concentrations of the youngest age group occurs off Rockabill, but their distribution is not well known until they reach about 15 cm length and can be taken in covered research trawls. These small fish are found scattered throughout the Irish Sea and are quite distinct from the populations fished commercially, although both types may occur in close association.

During the last three months of each year the availability of whiting increases, either because small shoals aggregate together, or because the fish themselves automatically become more vulnerable to capture, so that by the end of their second year of life they form commercially fishable populations. Again the largest concentration occurs off the east coast of Ireland, although this population may contain recruits from areas east of the Isle of Man. At the end of this, their second season of growth, the majority of I-group whiting are maturing for the first time at a size about equal to that of the smallest adult fish, which are also found in the County Down area. The availability of these, too, increases in the late autumn and the coincidence of the two sections of the population in the same area provides

the basis for the intensive County Down fishery. The shoals may coalesce at this time, or, as in the 1959–60 season when the length-distribution was noticeably bimodal, a proportion of the I-group shoals may maintain their integrity independent of the adult fish.

With the dispersal of the County Down fish in spring, the maturing I-group join the adult stocks which are redistributed more uniformly throughout the Irish Sea. The distinctive shoals of this particular age group then disappear, although the change is not complete until all the fish of one age group are mature at the end of their third year.

The Conway fishery is based upon a population of whiting of age groups II–IV. The tagging results show that some of these are recruited from the dispersing County Down population and a further contribution may come from the area directly to the north, between the Isle of Man and the English mainland. The evidence for this rests entirely upon the comparison of length-distributions in Figures 2(vi), (vii) and (viii) in Figure 2 (viii) the April sample from rectangle A 7 (off Cumberland) shows the absence of age groups represented at Conway (Figure 2(vi)) which were present off Cumberland in March (Figure 2(vii)) and had returned by May (Figure 2(ix)). Tagging experiments showed the movement of fish

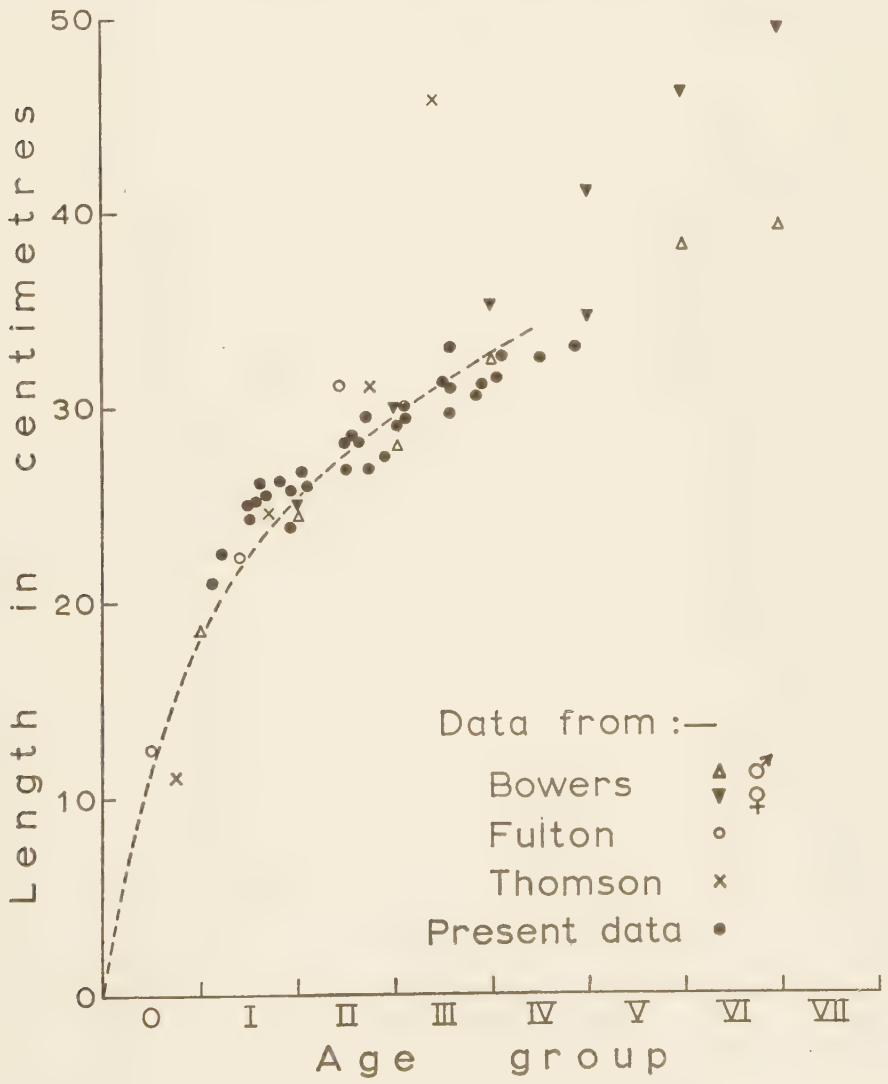

Fig. 10. *Curve of growth in length of Irish Sea whiting.*

from Conway into this area (see Figure 7) and Figure 2(ix) indicates a further decline in the modal length, which could be associated with the arrival of new recruits from the County Down fishery, via Conway, to these stocks of adult whiting. During the remainder of the year until October the mode progresses with the seasonal growth of whiting, and then a second downward shift of the mode implies further recruitment. This could reflect the appearance of whiting which do not recruit to the County Down fishery, although they behave in a similar way.

Other deep-water samples (Figures 2(v) and 3 C) suggest a further discontinuity in the shoaling behaviour of adult whiting, but the main conclusion to be drawn is the identification of the County Down population as the main concentration of juvenile whiting which are maturing for the first time. The fishery occurs at the end of the 'growing' season, when this age group reaches a size comparable to the adult stocks. After their first spawning they are recruited to the adult population and follow the wider distribution; some of the fish enter the Conway fishery and remain east of the Isle of Man, and others stay within the County Down area, providing the basic adult stock to which a new year-class will recruit the following year. The variable size of the run of fish in the County Down population depends upon the relative strength of the new year-class and its seasonal growth increment.

THE EFFECT OF FISHING UPON IRISH SEA WHITING

The foregoing discussion has made it clear that the distribution of whiting varies during their lifetime and that certain localities can be associated with particular age groups. There is no certainty that the proportion of the total stock of an age group which appears in one area will remain the same from year to year. In fact the tagging experiments showed that in 1958–9 emigration from the County Down fishery was much less than in the previous season and, as already noted, the behaviour of the 1958 class at the end of 1960 was also atypical. Evidently the distribution of the age groups critical to the County Down and Conway fisheries can be very variable. Furthermore, since the faster-growing fish within an age group, as well as the older fish, tend to be found in deeper water, it is difficult to form reliable estimates of the *total* abundance of any one age group (Hillis, pers. com.).

However, the County Down fishery, which is the most intensive area of exploitation, can be assessed as a unit stock within the Irish Sea, since the whiting are recruited first to this population, and subsequent losses to adjacent fisheries can be included in the effects of natural mortality and emigration. Detailed analysis of the age-distribution in the fishery, and the results of tagging, showed that the total seasonal loss from the fishery amounts to $Z = 1{\cdot}9$ (some 85%), of which about one half is attributable to fishing and the remainder to natural losses, mainly emigration to adjacent areas (see Part II of this publication). Subsequent recruitment of older age groups reduces the nett loss to $Z = 1{\cdot}4$ (75%). The initial seasonal loss is comparable with the decline in the Clyde whiting fishery recorded by Gambell (Part III of this publication), but in that stock there is no comparable recovery by the following year. There are several possible origins for these 'new' recruits in the County Down stock: (i) whiting that emigrate to adjacent areas in January-March may return to the County Down fishery in the subsequent season; (ii) a proportion of the seasonal decline may be caused by a change in 'availability' of whiting which remain within the same area and once more become available in the next season; (iii) new recruits may arrive from other areas. The available data suggest that a combination of all three factors may contribute to the fishery, in so far as the adult fraction of the County Down population is part of the more widely distributed stocks of mature fish.

The effects of fishing on whiting east of the Isle of Man are more difficult to evaluate since their recruitment from local juveniles and from the County Down area is variable, and in the other age groups further losses of older whiting into deeper water may lead to an overestimate of total mortality. At present it is not possible to distinguish these interrelationships from the true effects of fishing as opposed to natural mortality.

THE HISTORY OF THE IRISH SEA WHITING FISHERIES

HAVING analysed the overall structure of the fisheries it is now possible to re-examine the records with a better perspective, since the Irish, English and Welsh fleets fish different sections of the stocks and each fishery has a slightly different history.

The annual catches of whiting by England and Wales, the Republic of Ireland and Northern Ireland are given in Table 5 and illustrated in Figure 11, together with catch per unit effort data. For the pre-war years the latter are available for English and Welsh steam trawlers, but these have since been replaced by motor trawlers, and since the relative distribution of fishing and the fishing power of the pre-war and post-war fleets is not properly known, the early records cannot be directly compared with recent information. For the Republic of Ireland no detailed effort data are available, but records of the composition of their fishing fleet are given in the Annual Reports as the number of vessels in each tonnage class operating off the east coast. The main effort comes from vessels of over 10 tons and these have been totalled for each year, since the distribution within the larger sizes has not greatly changed. The best unit of effort available is the catch per boat/year. No continuous records are available for the Northern Irish fleet.

Table 5. *Historical records of the total catch (cwt) of whiting by England and Wales, Republic of Ireland, and Northern Ireland, together with indices of abundance where available (see text)*

Year	England and Wales	Cwt/100 hrs		Republic of Ireland	Cwt/Boat/ Year	Northern Ireland
		Steam	Motor			
1927	27,916			12,339		2,983
1928	23,758			10,863		2,353
1929	21,770			10,020		2,522
1930	28,131	10·8		10,942		3,218
1931	26,752	9·0		10,536		4,264
1932	22,071	7·9		9,656		3,779
1933	22,837	9·5		10,021		5,128
1934	28,646	10·6		16,437	222	4,713
1935	27,148	9·8		18,767	272	9,104
1936	29,695	13·1		15,461	215	17,442
1937	21,907	11·5		12,677	171	7,464
1938	50,120	21·5		16,520	240	17,061
1939				15,906	231	14,918
1940				18,754	293	29,695
1941				20,162		33,891
1942				31,527		55,016
1943				22,947		30,825
1944				39,128	711	64,619
1945				54,784	978	105,759
1946	40,282	92·8	37·1	46,383	760	130,391
1947	83,678	96·0	62·1	28,809	423	132,242
1948	127,814	68·7	61·3	32,262	424	119,659
1949	171,071	48·9	43·8	30,547	377	66,877
1950	83,355	33·7	34·0	20,726	230	32,896
1951	75,021	27·6	23·4	16,836	218	36,146
1952	71,241	27·9	34·7	15,887	201	44,153
1953	71,531	33·0	37·9	19,281	219	35,675
1954	85,628	35·2	32·9	37,335	410	59,481
1955	69,226	26·0	6·4	31,942	326	70,179
1956	59,603	23·0	17·2	40,076	514	48,443
1957	64,397	24·6	15·6	49,196	593	60,016
1958	55,663	26·9	23·7	69,957	777	76,356
1959	56,374	26·0	18·9	66,570	646	94,073
1960	75,668	22·5	45·9	54,661	520	27,824
1961	42,424	17·7	41·1			

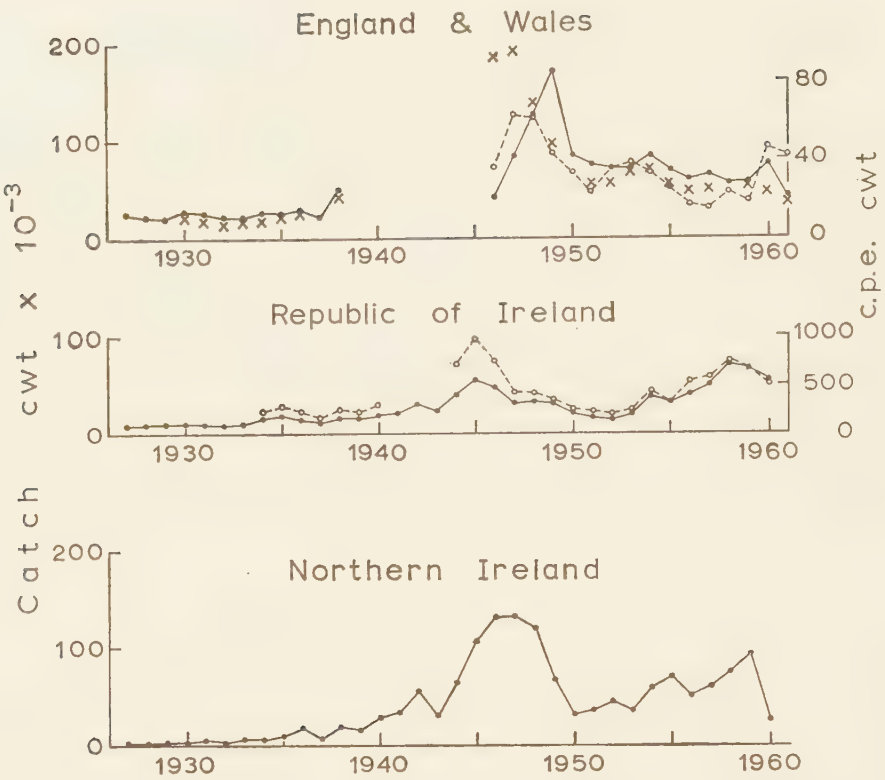

Fig. 11. *Annual total catch of whiting and catch per unit effort by England and Wales, the Republic of Ireland and Northern Ireland in the Irish Sea* 1927–61. *Total catch* (*cwt*) *shown by solid circles; c.p.e. for England and Wales* (*cwt*/100 *hrs*), *steam trawlers shown by crosses, motor trawlers by open circles; c.p.e. for Republic of Ireland* (*cwt*/*boat*/*year*) *shown by open circles.*

Up to the time when English records were interrupted by the war, the total catch of all three countries remained at a low level, as did the abundance measured by English steam trawlers. During these years the Irish fleets concentrated more on the summer herring fishery, but in 1937–8, instead of being laid up for the winter, these vessels began to turn to Danish seining for roundfish. This met with an immediate success, especially with the markets that became available as North Sea fishing was curtailed by the 1939–45 war. Scottish vessels from Lossiemouth began to work out of Northern Irish ports for the County Down winter season, and the total catch expanded rapidly. In 1938, 39 seiners were recorded as landing some 15,000 cwt from the whiting grounds, but by 1944 the fleet had grown to 66 vessels, excluding Scottish visitors, and the annual catches exceeded 100,000 cwt.

The English and Irish catch per unit effort data show that this expansion coincided with a dramatic increase in the recorded abundance of whiting (see Figure 11). This is of considerable interest because, in contrast to the North Sea fisheries, the cessation of English effort in the Irish Sea during the war was offset by the Irish expansion, so that these whiting stocks had no period of reduced fishing to account for the increase in abundance in the immediate post-war years. It is unlikely that such an abundant stock within 30 miles of the Irish coast could have remained undiscovered during the early 1930s; furthermore, although the Irish expansion was caused by greater concentration upon whiting, the fact that English post-war records still show the increase, and there is no reason to suppose that the pattern of English fishing had changed, leads one to conclude that there was a real increase in the abundance of whiting between 1942 and 1945. By 1946 landings were so heavy that it became necessary to restrict Northern Irish landings to a daily quota of 40–60 boxes per

boat/day in order to maintain the market. However, by 1948 Irish vessels reported a serious drop in catches which continued in 1949, to be followed in 1950 by marketing difficulties, and the boom was over.

No detailed records of length-distributions etc. exist for this period, but some estimate of the abundance on the County Down grounds alone can be gauged from the 40–60 box per boat/day quota imposed in Northern Ireland in 1946. This was obviously an underestimate of the true density which can be compared with Hillis's records for Irish boats in the 1959–60 season, when the catch per boat/day reached only 25–30 boxes at the beginning of the season. We can also deduce that in 1947 the whiting were relatively large, from the following quotation from the Northern Ireland Annual Report 1948–50:

> "The condition of the bulk of the whiting combined with a return to faulty gutting and poor handling led to the voluntary acceptance of 11 ins as the minimum length of whiting to be landed."

This minimum lay at about 28 cm and corresponds to the *mode* of the mean length-distribution for 1958–61 shown in Figure 2(iii).

The timing of this peak is also relevant. Fishermen from the Republic of Ireland fish the summer juvenile whiting to a greater extent than do the Northern Irish, and their catches show a peak in 1945. This is probably slightly earlier than the peak in County Down catches by Northern Irish vessels, and the peak abundance recorded by English vessels fishing predominantly east of the Isle of Man occurred later still, in 1946–7. The progression between peak catches by the Republic of Ireland and England is clear, and it seems that there were a number of phenomenally strong year-classes which, by 1947, had built up a population of adult whiting (III+?) which gave the peak English catches and led to the acceptance of a size limit in Northern Irish ports.

After 1948 these strong year-classes rapidly passed out of the commercial fishery and were succeeded by poorer ones, so that between 1950 and 1955 the abundance returned to its pre-war level as recorded by the Irish statistics of catch/boat/year, and also by the English steam trawlers' catches per unit effort, if intervening changes in fishing power are taken into account.

These post-war changes in abundance are shown in more detail in Figure 12 because since 1953 Irish and English catches have followed dissimilar trends. The catch per unit effort (by weight) by Irish boats increased almost to the 1945 level by 1958, but, judging from the quota accepted in 1946, the landings then excluded the smallest fish now being landed; hence the landings per unit effort in 1946 give an underestimate of the abundance of all sizes of fish. English catches have also increased since the very poor fishing of 1955, but the improvement occurred slightly later than in the Irish catches, reaching a peak in 1960.

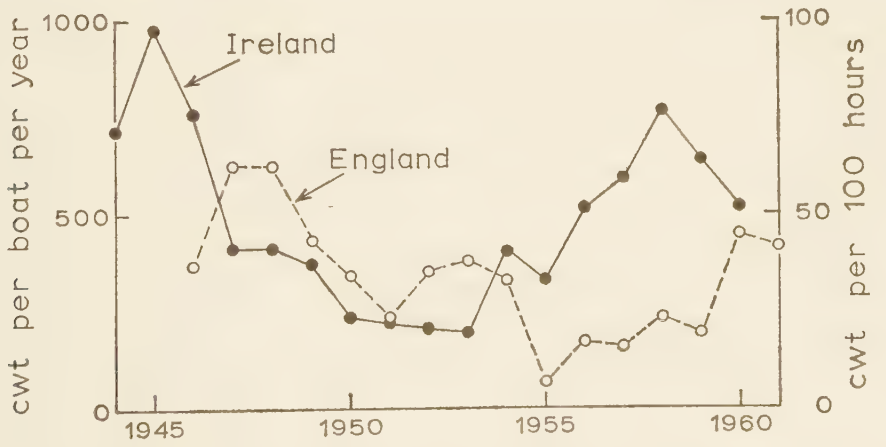

Fig. 12. *Post-war changes in abundance of Irish Sea whiting recorded by English data, in cwt/100 hrs fishing by motor trawlers, and by Republic of Ireland data, in cwt/boat/year.*

This again reflects the concentration of English fishermen upon adult whiting, but it does not necessarily imply the progression of the same fish from area to area. If the relative year-class strengths were much the same in adjacent independent stocks, the same trends would emerge. Consequently, although these records confirm the different fishing interests of the English and Irish fishermen, there is no clear evidence that the catches in the County Down fishery influence the subsequent abundance of whiting east of the Isle of Man.

SUMMARY

THE commercial catch statistics of the Irish Sea whiting fisheries have been analysed in combination with the age- and length-composition data collected since 1957.

There are at least two types of whiting population, which can be distinguished by their length- and age-compositions. The division is believed to be related to their maturity, in that west of the Isle of Man principal aggregations of O- and I-group juvenile whiting occur on the Rockabill and County Down grounds, whilst the adult whiting are more uniformly distributed over the whole of the Irish Sea. The change in distribution occurs between the second and third year of life as whiting grow and reach maturity. The recruitment of juveniles to the mature stock takes place in the County Down area where both groups occur together, providing the basis for the seasonal fishery. English and Welsh fleets exploit the more widely distributed adults to a greater extent than do the Irish fleets, and there is some evidence that still older and larger whiting occur in deep water.

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Part II: English Whiting Tagging Experiments in the Irish Sea

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INTRODUCTION

At certain times of the year the annual cycle of behaviour of the whiting, *Merlangius merlangus* L., leads to the formation of locally dense concentrations of fish. In the Irish Sea this movement of the stock provides the basis for a specialist 'single species' fishery which occurs west of the Isle of Man, off the coast of County Down (Northern Ireland) during the winter months, October March. The importance of this fishery within the context of the whiting population throughout ICES Statistical Region VIIA can be seen from Table 1, which gives the proportion of the total whiting catch landed from the County Down population by fishermen from England and Wales, the Republic of Ireland, and Northern Ireland. During the three years 1958-60, of a total catch of 29,000 tons of whiting from the Region, 20,000 tons came from the County Down fishery.

Table 1. *The total catch of whiting from Region VIIA and within the County Down fishery by England and Wales, the Republic of Ireland, and Northern Ireland,* 1958–60 (*cwt gutted*)

Year	Total catch from Region VIIA	Total catch from County Down	% of total from County Down
1958	201,976	155,326	76·9
1959	217,017	158,750	73·2
1960	158,153	88,909	56·2
Total 1958–60	577,146	402,985	

The fish in this population are characteristically smaller and younger than in most whiting fisheries and it has been suggested that the County Down fishery exploits juvenile fish that would otherwise recruit to adjacent whiting fisheries, thus influencing the yield in these other areas. In view of the obvious importance of the fishery, three large-scale tagging experiments have been carried out to determine whether or not this suggestion is correct, and if so, to find out the effect of present fishing upon stocks outside the County Down fishery, in addition to estimating the fishing rate upon the County Down population itself.

METHOD

During the 1957–8 season the R.V. *PLATESSA* made two tagging cruises (Cruises XVIII and XIX/57, 15–27 November and 2–16 December), using a Danish seine. A third experiment was made in the 1958–9 season (Cruise XVIII/58, 6–10 December). The releases in these three experiments totalled 2,901, 3,304 and 1,887 whiting respectively. Some continuity of scientific personnel was maintained throughout the series of experiments, in order that the handling, classification and cage release of all fish should be consistent, so far as this was possible.

The reporting of recaptures by fishermen is believed to have been very efficient during these experiments, owing to the small size of the Irish ports and the general interest taken in the experiments. Very shortly after the releases a number of returns came from consumers, but once the experiments were publicized all returns came from fishermen themselves.

THE EFFECT OF CONDITION UPON RETURN RATE

THE whiting were graded, according to the degree of scaling, as 'good' (G), 'medium' (M) or 'poor' (P), and according to their activity in the marking tanks as 'active floaters' (A), 'sluggish floaters' (B), and 'sinkers' (S) – the fish that were able to go to the bottom of the tanks. The activity categories were especially difficult to standardize, and in a preliminary analysis of the effects of the condition of the fish upon the recapture rate, Beverton and Bedford (1963a) found very little difference between the proportion returned of categories A and B, although 'sinkers' gave variable results. They did find a consistent decrease in returns with increasing scale damage, and in a second paper (1963b) they also demonstrated a significant decline in the proportion returned of all categories as the length of time whiting were held on board increased. This was shown in the two largest hauls from which material was taken, but since the majority of individual hauls yielded only small numbers of whiting suitable for marking, this time factor has been ignored in subsequent analysis. Nevertheless, it is clear from their results that prolonged retention of fish before or after marking has an adverse effect upon subsequent survival.

In view of the similarity in the returns of categories A and B found by Beverton and Bedford, the releases and recaptures during the three experiments have been reclassified as G(A + B), M(A + B), P(A + B), and all 'sinkers' (see Table 2). Subsequently the returns of category P and all 'sinkers' have been combined, since Table 2B (the percentage returned in each category) shows very little difference between the two groups except in the first experiment. The reason for this apparently anomalous result is unknown. In addition, the results of two experiments carried out in exactly the same way in the Brixham (South Devon) autumn whiting fishery are included in Table 2, to amplify the data relating to the effects of condition upon recapture rate.

In their analysis of the recaptures Beverton and Bedford took the category M as reference and calculated indices for the other categories, relative to it. In the present work the procedure was essentially the same, except for the use of category G as reference instead of M.

The fishing effort on each tagged population was not uniform, resulting in the absolute proportion of recaptures being different for each experiment, yet the return rates of the categories M and P were consistent relative to G. This relationship would represent the basis of a correction for the initial tagging mortality, if it could be used to extrapolate the return rate of an undamaged fish. Strictly speaking this is not possible, because the degree of damage relating to the various categories could not be measured, but Beverton and Bedford in their second paper (*loc. cit.*) were able to estimate, by extrapolation from the returns of fish held on board for varying lengths of time, that the maximum return rate would be rather less than 35 per cent. This is higher than the mean proportion recaptured of the G category (22·07%) in the Irish Sea whiting experiments, implying some tagging mortality even of this the best category. In order to obtain a provisional correction for the initial tagging mortality the simplest assumption has been taken, viz. that the three categories are equidistant in the degree of damage recorded, and that the category G is intermediate between M and a hypothetical undamaged fish, O. This is illustrated in Figure 1, in which the intercept (A) represents a maximum return rate of 28%, which is not inconsistent with Beverton and Bedford's results. The relationship shown gives the following estimates of the initial mortality of each category: G, 22%; M, 44%; P, 66%; but clearly, although the ratios between G, M and P will remain constant, the percentage initial mortality depends critically upon the choice of origin relating G to the undamaged fish. This is discussed further, giving limiting values of the origin, in the section on 'Theoretical considerations', below. The figures

Table 2A. *The classification of actual releases of tagged whiting*

Experiment	Total releases	Release categories				Recaptures				
		G(A + B)	M(A + B)	P(A + B)	Sinkers	G(A + B)	M(A + B)	P(A + B)	Sinkers	Total
PLATESSA XVIII/1957	2,901	943	1,055	376	527	188	167	36	111	502
PLATESSA XIX/1957	3,304	343	1,147	1,038	776	79	213	79	76	447
PLATESSA XVIII/1958	1,887	310	859	471	247	72	155	43	25	295
Brixham/1958	1,900	288	964	523	125	61	139	12	8	220
Brixham/1959	2,478	391	1,045	951	91	111	230	66	10	417

Table 2B. *Percentage recaptures in each category*

	PLATESSA XVIII/1957	PLATESSA XIX/1957	PLATESSA XVIII/1958	Brixham/1958	Brixham/1959
G(A + B)	19·94 (1·00)	23·03 (1·00)	23·23 (1·00)	21·18 (1·00)	28·39 (1·00)
M(A + B)	15·83 (0·79)	18·57 (0·81)	18·04 (0·78)	14·42 (0·68)	22·00 (0·77)
P(A + B)	9·57	7·61	9·13	2·29	6·94
Sinkers	21·06	9·79	10·12	6·40	10·99
P(A + B) + Sinkers	16·288 (0·82)	8·54 (0·37)	9·47 (0·41)	3·09 (0·15)	7·29 (0·26)

The figures in brackets refer the recaptures of each category to the recaptures of category G, which is regarded as unity.

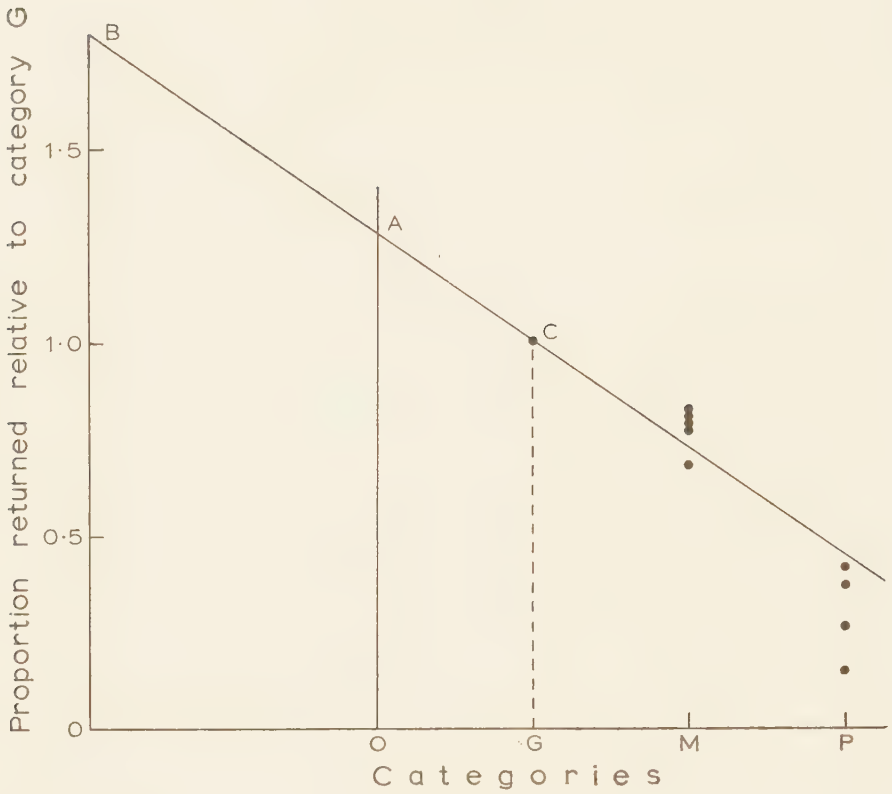

Fig. 1. *The relative return rates of whiting which at release were in three categories of scale damage, G, M, and P.*

quoted above are taken as the first estimate of the initial mortality and have been used to correct the classified actual releases to give a total effective release in each experiment. The subsequent behaviour of these fish is assumed to be independent of their condition when tagged.

THE DISTRIBUTION OF RECAPTURES

The effective releases are given in Table 3, with the distribution of returns by calendar months from the time of marking and by the source of recapture. The recapture period O repesents the month in which marking took place, e.g. from the cruise *PLATESSA* XVIII/57 eighty-three tags were returned by British and Irish fishermen between 15 and 30 November.

The distribution of returns with time was similar in each experiment, showing a high rate of recapture within the County Down fishery during the whiting season, very few during the following summer, and a slight increase at the beginning of the following season. In all three experiments only twelve tags were returned after one year or longer at liberty.

The distribution of returns between different sources is shown in Table 4.

The geographical distribution of known recapture positions is shown in Figure 6 of Part I. Relatively few tags were returned from outside the marking area, but of these the majority were taken in March and April. Continental vessels recorded a greater number than English vessels from the rectangles ZZ and A 5, 6, 7 and 8, but this probably reflects a difference in the fishing interests of the two fleets. The returns from outside the marking area were very much lower in 1959, following the 1958 9 experiment, although English fishing effort was much the same as in 1958.

Table 3. *The distribution of tagged whiting recaptures by time and source*

(a)	Within marking area	English, Irish, Northern Irish vessels
(b)	Within marking area	Continental vessels
(c)	Rectangles ZZ and A, 5, 6, 7, 8	English vessels
(d)	Rectangles ZZ and A, 5, 6, 7, 8	Continental vessels
(e)	Elsewhere	All vessels
(f)	Unknown	

Experiment		Calendar months at liberty													Recapture date unknown	Total	
		0	1	2	3	4	5	6	7	8	9	10	11	12+			
PLATESSA XVIII/1957	(a)	83	97	89	13	18	20	2	1	2	2	2	6	6		341	
	(b)		7	25	10	4	7	1	2	1		2				59	
Actual releases 2,901	(c)				1		2	2		1						6	
Effective releases 1,634	(d)				7	4	7	1								19	
	(e)		1	1	2	1	3	4			1			3		16	
	(f)	12	25	4		9	7		2			1	1			61	502
PLATESSA XIX/1957	(a)	161	121	36	13	16	4			5		1	1	1		359	
	(b)	3	10	5	4	2	2				1					27	
Actual releases 3,304	(c)				1	4	1									6	
Effective releases 1,527	(d)			1	4	7										12	
	(e)	1	3	4	2	2	1		1			1				15	
	(f)	8	5	4	6	1	2								2	28	447
PLATESSA XVIII/1958	(a)	96	92	29	28	6	2	4		1	2	4	4			268	
	(b)	2	6		6	1										15	
Actual releases 1,887	(c)				1											1	
Effective releases 967	(d)			1	1											2	
	(e)		1		1	1								2		5	
	(f)	1		1	1		1									4	295

Table 4. *The distribution of tagged whiting returns between different sources*

Source		Percentage of total recaptures			
		Cruise XVIII/1957	Cruise XIX/1957	Cruise XVIII/1958	Total
English Northern Ireland, Republic of Ireland	Marking area	67·9	80·5	90·8	77·9
Continental	Marking area	11·8	6·1	5·1	8·1
English	Rectangles ZZ and A, 5, 6, 7, 8	1·2	1·3	0·3	1·0
Continental	Rectangles ZZ and A, 5, 6, 7, 8	3·8	2·7	0·7	2·7
All nationalities	Elsewhere	3·2	3·1	1·7	2·8
Unknown		12·1	6·3	1·4	7·5

The fishing intensity in the County Down fishery is greater than in the adjacent areas; hence the distribution of returns between the areas does not give a direct estimate of the proportion of the tagged whiting that had moved out of the marking area. A more detailed analysis has been made in order to take this emigration into account in assessing the effect of fishing upon the County Down stock, and to estimate the emigrants as a proportion of the total stock.

THEORETICAL CONSIDERATIONS

FROM the description given above it can be seen that this County Down fishery has a very restricted season, and that relatively few whiting are recaptured after six months at liberty. For this reason it has not been possible to determine the rate of total mortality from the decline, with time, of the total number of tags returned. Instead the basic parameters of mortality have been assessed by Gulland's method of combining the known fishing effort with an estimate of the catchability coefficient, q, determined from tag recapture data (Gulland, 1963).

Using the international notation, the numbers of tagged fish, N_t, present in the locality of the release point during the period immediately after tagging is given by

$$N_t = N_0 e^{-(F + X + E)t} \qquad (1)$$

where N_0 is the effective number of tagged fish released,
F is the fishing mortality in the locality,
X represents Type 2 losses, as defined by Beverton and Holt (1957),
E is the loss by emigration from the locality of release.

If the numbers do not change very greatly during a time interval, t, then to a close approximation

$$\bar{N}_t = N_0 e^{-(F + X + E)t} \qquad (2)$$

where $\bar{N}_t$ is the mean number of tagged fish present.

The rate of recapture of tagged fish, i.e. the fishing mortality, is related to the fishing intensity (f) in the tagging area by the catchability coefficient q ($F = qf$); therefore $n_t/f_t = q\bar{N}_t$, where n_t/f_t is the number of tags recaptured per unit fishing intensity. Substituting in (2) for $\bar{N}_t$

$$\frac{n_t}{f_t} = q\, N_0 e^{-(F + X + E)t}$$

and

$$\log_e \frac{n_t}{f_t} = \log_e qN_0 + (F + X + E)t \qquad \text{(see Gulland, 1963).}$$

This is analogous to the conventional procedure of estimating (F + M) from a survival curve. In this instance a logarithmic plot of tags returned per unit fishing intensity against time will have an intercept on the y axis equal to $\log_e qN_0$, and a slope (F + X + E). (Tags returned are taken to be the same as tags recaptured, since the efficiency of reporting is believed to have been very high.) The results of similar experiments can be compared by plotting the tags returned per unit intensity as a percentage of the initial releases. The intercept is then a direct estimate of q, expressed as the percentage of the tagged population removed per unit intensity.

Where the experiment is based upon a widely distributed stock the value of (F + X + E) will change as the tagged fish move out from the release point into the untagged stock. The rate of dispersal will be initially relatively rapid, but at some point in time after release this movement will be balanced by the random movements of the tagged fish which cause them to return towards the tagging area. The tagged population can then be said to be uniformly distributed throughout the untagged stock.

In these experiments the untagged population of whiting which recruited to the County Down seasonal fishery occupied an area of approximately two thirty-mile square statistical rectangles. The tag releases were well distributed and since the returns from known positions give a rate of movement of 0·25 miles/day, it can be concluded that uniform distribution within the untagged population could have been achieved within one month of release. Thereafter the behaviour of the tagged and untagged populations can be assumed to be identical.

Furthermore, the small geographical area of the fishery permits the fishing effort to be taken as equivalent to the fishing intensity.

RESULTS

In Table 5 the tags returned per unit fishing intensity in the three Irish Sea whiting experiments are calculated for returns from England, Northern Ireland and the Republic of Ireland. The effort has been expressed as the number of hours fishing by Northern Irish seiners that would be required to take the total seasonal catch for these countries. The number of effective releases is for the present taken as the estimate given in Table 3.

The results are plotted in Figure 2, where the time axes for the 1957 experiments have been adjusted to give the same origin. Regressions fitted by least squares show that the two 1957 experiments gave closely comparable results, with an intercept on the log scale of −0·6, corresponding to q = 0·55% per 100 hours fishing, and a slope (F + X + E) = 1·13 per month. Towards the end of the experiment the tag density shows an increase associated with a small recovery of the fishery in April known as the 'April glut'.

The plot of results from the 1958 experiment has the same intercept but a lower slope, (F + X + E) = 0·68 per month.

Assuming complete mixing of the tagged and untagged populations, and knowing the fishing effort, this value of q can be used to give direct estimates of the fishing mortality on the stock. Thus we have qf = 0·28 per month in 1957–8 and 0·24 per month in 1958–9, since fishing effort was much the same in both seasons. This is less than either value of (F + X + E), implying a high level of (X + E), with an added discrepancy between the values for the two seasons.

As the initial tagging mortality and the non-reporting of tags have already been discussed, the remaining sources of error comprising (X + E) (Beverton and Holt's Type 2 losses, and Ricker's Type B losses) are:

(i) the loss of tags, occurring at a steady instantaneous rate throughout the experiment,
(ii) the additional mortality due to tagging, occurring throughout the experiment,
(iii) the emigration of fish.

The method of marking used throughout these experiments was the same; therefore (ii) above would have been constant throughout the series and cannot be the source of the discrepancy between the value of (X + E) in the two seasons. More probably this should

Table 5. *Stages in the estimation of q, the catchability coefficient, for whiting fished in the County Down seasonal fishery*

PLATESSA CRUISE XVIII/1957, 15–27 NOVEMBER

	November	December	January	February	March	April
Total catch (cwt) in County Down area by:						
Northern Ireland	11,467	11,801	8,222	4,152	4,127	4,461
Republic of Ireland	7,270	5,473	5,572	1,295	1,267	1,807
England	10,329	3,355	1,547	240	1,109	1,487
Total	29,066	20,629	15,341	5,687	6,503	7,755
Density (cwt/100 hrs, Northern Irish seiners)	820·04	674·73	340·00	99·49	126·68	193·12
Effective effort (hrs)	3,544	3,057	4,512	5,716	5,133	4,016
Effort on tagged fish (i.e. correction for November)	1,200	3,057	4,512	5,716	5,133	4,016
Tags returned (A)	83	97	89	13	18	20
Tags/100 hrs (B)	6·92	3·17	1·97	0·23	0·35	0·50
Tags/100 hrs/effective release (C)	0·424	0·194	0·121	0·014	0·021	0·031
Log_e C	−0·858	−1·640	2·112	−4·269	3·863	3·475

PLATESSA CRUISE XIX/1957, 2 16 DECEMBER

		December	January	February	March	April
Effective effort (hrs)		2,000	4,512	5,716	5,133	4,016
A		161	121	36	13	16
B		8·05	2·68	0·63	0·25	0·40
C		0·527	0·176	0·041	0·016	0·026
Log_e C		−0·641	−1·737	−3·194	−4·135	3·650

PLATESSA CRUISE XVIII/1958, 6–10 DECEMBER

	November	December	January	February	March	April
Total catch (cwt) in County Down area by:						
Northern Ireland	32,840	9,414	9,241	5,701	5,253	2,128
Republic of Ireland	16,765	9,257	5,416	2,423	1,036	690
England	1,596	238	66	268	967	504
Total	51,201	18,909	14,723	8,392	7,256	3,322
Density (cwt/100 hrs, Northern Irish seiners)	855·75	469·10	377·02	246·06	323·06	169·66
Effective effort (hrs)	5,976	4,031	3,905	3,411	2,246	1,958
Effort on tagged fish		2,700	3,905	3,411	2,246	1,958
A		96	92	29	28	6
B		3·56	2·36	0·85	1·25	0·31
C		0·368	0·244	0·088	0·129	0·032
Log_e C		−1·000	−1·411	−2·430	−2·048	3·442

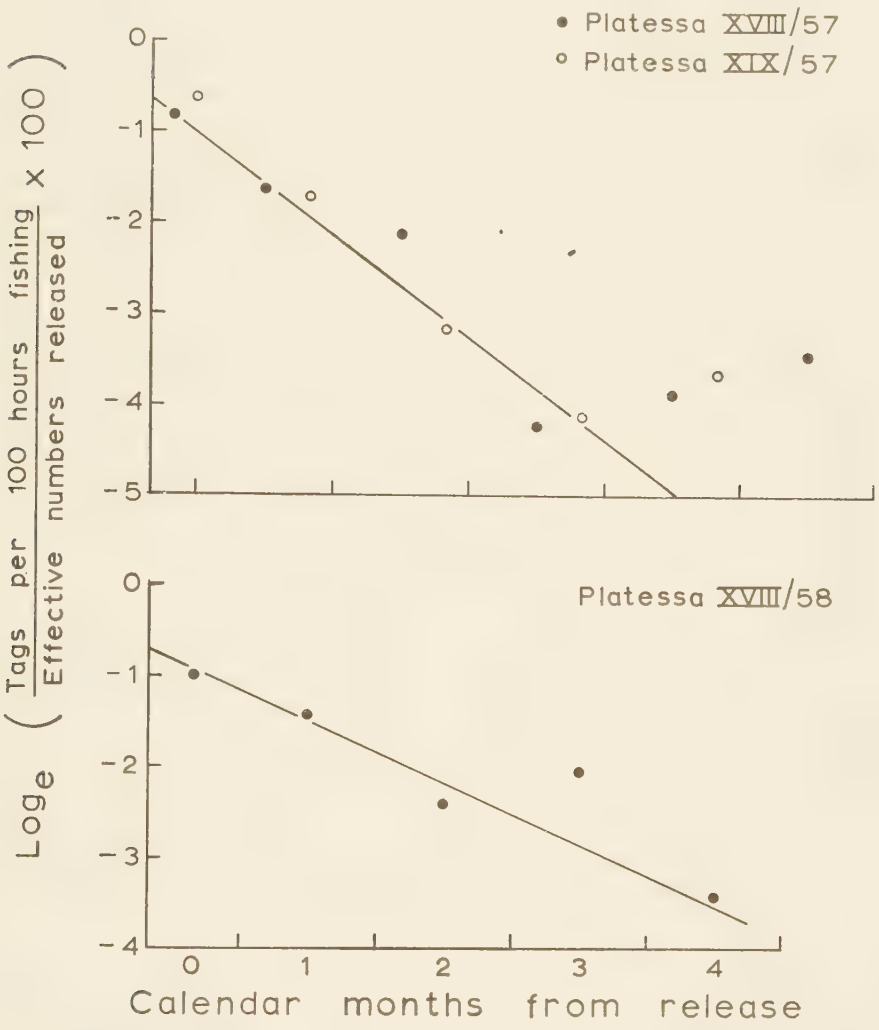

Fig. 2. *The regression of numbers of tagged whiting returned per unit effort with time.*

be attributed to differences in natural mortality or emigration. Table 4 records that in the two experiments of 1957–8 returns from outside the marking area totalled 8·2 and 7·1 per cent respectively of all returns, but this proportion only amounted to 2·7 per cent in 1958–9 although, so far as it is known, fishing effort was comparable in the two periods and the efficiency of reporting is not likely to have changed. This suggests that the differences in the value of (X + E) for the two seasons may lie in a variation in the rate of emigration from the County Down stock.

Further information relating to the composition of the coefficient (F + X + E) can be obtained from the declining abundance of the untagged population, as shown by the catch per unit effort in the commercial fishing records. This is plotted in Figure 3. Regressions representing the decline (F + M + E) have been fitted by eye for the relevant months during which tags were returned in appreciable numbers. These regressions have the values (F + M + E) = 0·70 per month in 1957–8 and (F + M + E) = 0·34 per month in 1958–9, and can be combined with the values of (F + X + E) and F to give a measure of the difference in emigration between the two seasons. The basic values are set out in Table 6, from which

1957–8 $(X + M + 2E_{(i)}) = 1{\cdot}27$

and 1958–9 $(X + M + 2E_{(ii)}) = 0{\cdot}54$

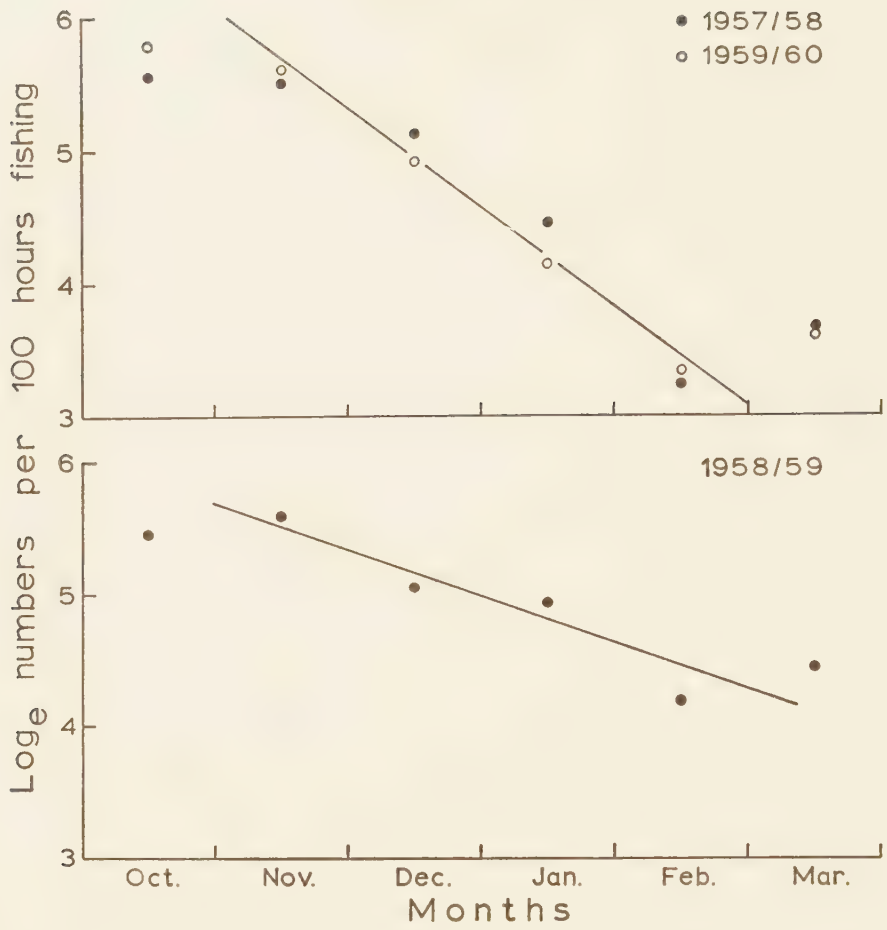

Fig. 3. *The seasonal changes in abundance of whiting in the County Down stock.*

Assuming X and M to be equal in the two experiments this gives the difference $E_{(i)} - E_{(ii)} = 0{\cdot}36$. Subtracting this from the value of (M + E) in the 1957–8 season shows that the value of M itself would not exceed 0·06, and this, when subtracted from the value (M + E) = 0·10 in the 1958–9 season, leaves the value 0·04 to represent emigration in that season. However, the data given in Table 4 indicate that the emigration during this second season was one third that of the previous season, and so the value 0·04 must underestimate this emigration. It is therefore concluded that natural mortality must be negligible during this period, i.e. $<0{\cdot}05$ per month. This is not surprising, since there are few predators in the area that could feed on whiting of a marketable size (>25 cm), although predation on O-group whiting (*ca.* 15 cm) by larger whiting may be severe.

The distinction of F from the other parameters depends critically upon the value of q, which itself rests upon the correction for initial tagging mortality. This is uncertain but, having demonstrated a possible relationship between the actual and effective releases, it is

Table 6. *Estimates of monthly parameter values for the whiting of the County Down fishery*

Season	F + X + E	F + M + E	F	X + E	M + E	X − M
1957–8	1·13	0·70	0·28	0·85	0·42	0·43
1958–9	0·68	0·34	0·24	0·44	0·10	0·34

possible to establish limits within which the true number of effective releases, and hence q, must lie.

The coefficient q was the same in both 1957–8 and 1958–9, but the total mortality was less in the second season. The value of q therefore has an upper limit that would generate the observed total mortality in 1958–9, assuming emigration and natural mortality to be nil. This upper limit has the mean value $q_2 = 0{\cdot}77\%$ per 100 hours fishing; the initial number of effective releases must therefore be reduced in the ratio of $q/q_2 = 0{\cdot}55/0{\cdot}77$. The revised number of effective releases was then distributed between the categories G, M and P to give a new intercept (B) shown in Figure 1.

A lower limit, q_3, can be established by assuming that all fish of category G would have survived (Figure 1, intercept C). Correcting this for mortality in categories M and P, the effective releases can be treated in the same way as the initial correction, giving a value of $q_3 = 0{\cdot}41\%$ per 100 hours fishing.

These limits are corrections for Beverton and Holt's Type 1 losses and have no effect upon the estimate of (F + X + E); hence the slopes of the regressions in Figure 3 are unchanged and a combination of limiting parameter values can be constructed as before (Table 7).

Table 7. *Estimates of monthly parameters at limiting values of q, for the whiting of the County Down fishery*

A. Lower limit, q = 0·41% per 100 hours

Season	F + X + E	F + M + E	F	X + E	M + E	X − M
1957–8	1·13	0·70	0·21	0·92	0·49	0·43
1958–9	0·68	0·34	0·18	0·50	0·16	0·34

B. Upper limit, q = 0·77% per 100 hours

1957–8	1·13	0·70	0·39	0·74	0·31	0·43
1958–9	0·68	0·34	0·34	0·34	—	0·34

The range of effective releases is almost doubled between these limits and represents an effect comparable to 50% of tags recaptured not being reported. This is Beverton and Holt's second Type 1 loss, which affects the value of fishing mortality but not the total mortality. It has not been dealt with further here because the reporting is believed to have been very good in the small Irish ports. A possible 10% loss through non-reporting could easily be accommodated within the range given.

The apparent smallness of the range is misleading when expressed on a monthly basis. In a six-month season total fishing mortality would be high, but its precise value is difficult to determine when variable emigration progressively reduces the proportion of the total stock which is exposed to the fishing effort. In fact the monthly values of F, E or M cannot be determined accurately within the range given, without further data. Some indication of the most probable value of q can be gained by applying these parameters to actual catch data.

The seasonal peak in abundance of whiting in the County Down fishery occurred in October during the 1957–8 and 1959–60 seasons, and in November during the 1958–9 season (see Figure 3). Since the rate of reduction of abundance in each season was constant after November it can be assumed that seasonal recruitment is complete by this time. Then, knowing the catch per unit effort and the total catch in November, the three possible values of q can be used to give estimates of stock biomass in that month, using the formula

$$W_1 = \frac{Y_w(F + X + E)}{F(1 - e^{-(F + M + E)})} .$$

The total rate of reduction between November and the end of the season is calculated from the indices of abundance to give the total loss by weight from the biomass of the stock over the period; in Table 8 this loss is compared with the recorded total catch, in order to establish the proportion of the decline that can be attributed to fishing. It is important to note that during the 1958–9 season, for both the initial estimate of q and its upper limit, the seasonal catch is greater than the total decrease in biomass of the population. For this to occur would require further immigration to the stock. There is a slight increase in abundance at the end of the season, which has been taken into account in assessing the total decrease in biomass, but this is thought to be associated with a change in the availability of whiting that have remained in the same area. Indeed, such a change could account for much of the value of (M + E). There is no evidence of the required increase in total stock abundance after November through the arrival of new recruits, and since the returns of tags from outside the marking area show that at least some emigration occurred during the 1958–9 season, it is concluded that these two provisional estimates of q (q = 0·55% and q = 0·77%) overestimate the effectiveness of the fishing. The true value of q is thought to be slightly below the original estimate of q = 0·55% per 100 hours fishing.

This means that in 1957–8 the loss by emigration was considerable: the parameter values are thought to be approximately F = 1·0 and (M + E) = 0·9. The data for 1959–60 are also included in Table 8, showing that this season is more typical of the fishing: the 1958–9 season was regarded by the fishermen as anomalous, since the fishery was unusually good during the second half of the season owing to the atypically low rate of emigration.

At the same time a logarithmic plot of the abundance of different year-classes taken from age samples collected at Northern Irish ports during the County Down seasons 1957–60 gives an independent annual estimate of (Z + E) = (F + M + E) (Figure 4). Seasonal variation is marked, but the greater proportion of this scatter is associated with different fishing strategy, i.e. boats are fishing exclusively for whiting only during the fourth quarter of the year, and the indices are therefore not strictly comparable between consecutive quarters. The regressions shown have been fitted by eye to express the decline in each year-class between corresponding quarters of successive years. These give a value of (Z + E) = 1·4 for the 1955, 1956 and 1957 year-classes.

Taking the 1957–8 and 1959–60 seasons as typical of the fishery, the data are interpreted as showing a seasonal total reduction of approximately (Z + E) = 1·9 (85%), sub-divided as F = 1·0, (M + E) = 0·9; i.e. fishing by England and Wales, the Republic of Ireland, and Northern Ireland removes 40–45% of the County Down whiting population during the season. However, there is a subsequent change of availability of whiting in the same area, or a return of emigrants, or recruitment of older fish from a different source, which offsets both this loss and other losses by fishing during the remainder of the year, so that the net annual reduction coefficient of the population is (Z + E) = 1·4 or 75%.

The additional fishing mortality during the remainder of the year is obscured by the recruitment of a new year-class, but a comparison of the estimated total catch of particular age groups in the fourth and first quarters with catches in the second and third quarters gives the catches during the latter period as only one fifth of those taken during the main season, and not all of this is taken in the area of the County Down fishery. Continental fishing activity also removes a fraction, which cannot be ascertained from published statistics, but for a comparison of these tag returns with those returned by England and Wales, the Republic of Ireland, and Northern Ireland this fishing effort in the County Down area is thought not to exceed one tenth of the effort by the three main countries. These two factors, i.e. fishing outside the County Down season proper and fishing by continental countries, could cause a further 10% reduction in the stock which is not completely accounted for by analysis of the tagging experiments; hence a reasonable minimum estimate of the net annual rate of reduction in the County Down fishery would be (Z + E) = 1·4 (75%), of which F = 0·9 (50%) and (M + E) = 0·5 (25%).

The other-loss rate (X − M), which is included in Table 6, implies that twelve months after the release few fish will survive with a tag still attached. For example, using a value (X − M) = 0·35 per month and including the effects of fishing, not more than fifty fish from the two 1957–8 experiments would be surviving at liberty at the beginning of the

Table 8. *A comparison between the total catch of whiting and the total loss calculated from estimates of abundance in November and at the end of the season*

	November	December	January	February	March		q (% per 100 hrs fishing)		
							q = 0·41	q = 0·55	q = 0·77
1957–8									
A. Total catch (cwt) (England, Northern Ireland and Republic of Ireland)	29,066	20,629	15,341	5,687	6,503	Total stock in November (cwt)	200,036	149,118	106,513
						Z	1·87	1·87	1·87
B. Cwt/100 hrs (Northern Irish Seine)	820·04	674·73	340·00	99·49	126·68	Total loss (cwt)	169,210	126,139	90,099
						Total catch (cwt)	77,226	77,226	77,226
						F	0·85	1·14	1·60
C. f (hrs)	3,544	3,057	4,512	5,716	5,133				
						M + E	1·02	0·73	0·27
1958–9									
A.	51,201	18,909	14,723	8,392	7,256	Total stock in November (cwt)	208,726	155,595	111,140
						Z	0·97	0·97	0·97
B.	855·75	469·10	377·02	246·06	323·06	Total loss (cwt)	129,598	96,609	69,007
						Total catch (cwt)	100,481	100,481	100,481
						F	0·75	1·01	1·41
C.	5,983	4,031	3,905	3,411	2,246				
						M + E	0·22	− 0·04	−0·44
1959–60									
A.	32,033	10,685	10,533	3,437	4,770	Total stock in November (cwt)	195,177	145,495	103,925
						Z	1·92	1·92	1·92
B.	800·25	402·27	206·98	91·40	116·93	Total loss (cwt)	166,564	124,165	88,690
						Total catch (cwt)	61,458	61,458	61,458
						F	0·71	0·95	1·33
C.	4,003	2,656	5,089	3,760	4,079				
						M + E	1·21	0·97	0·59

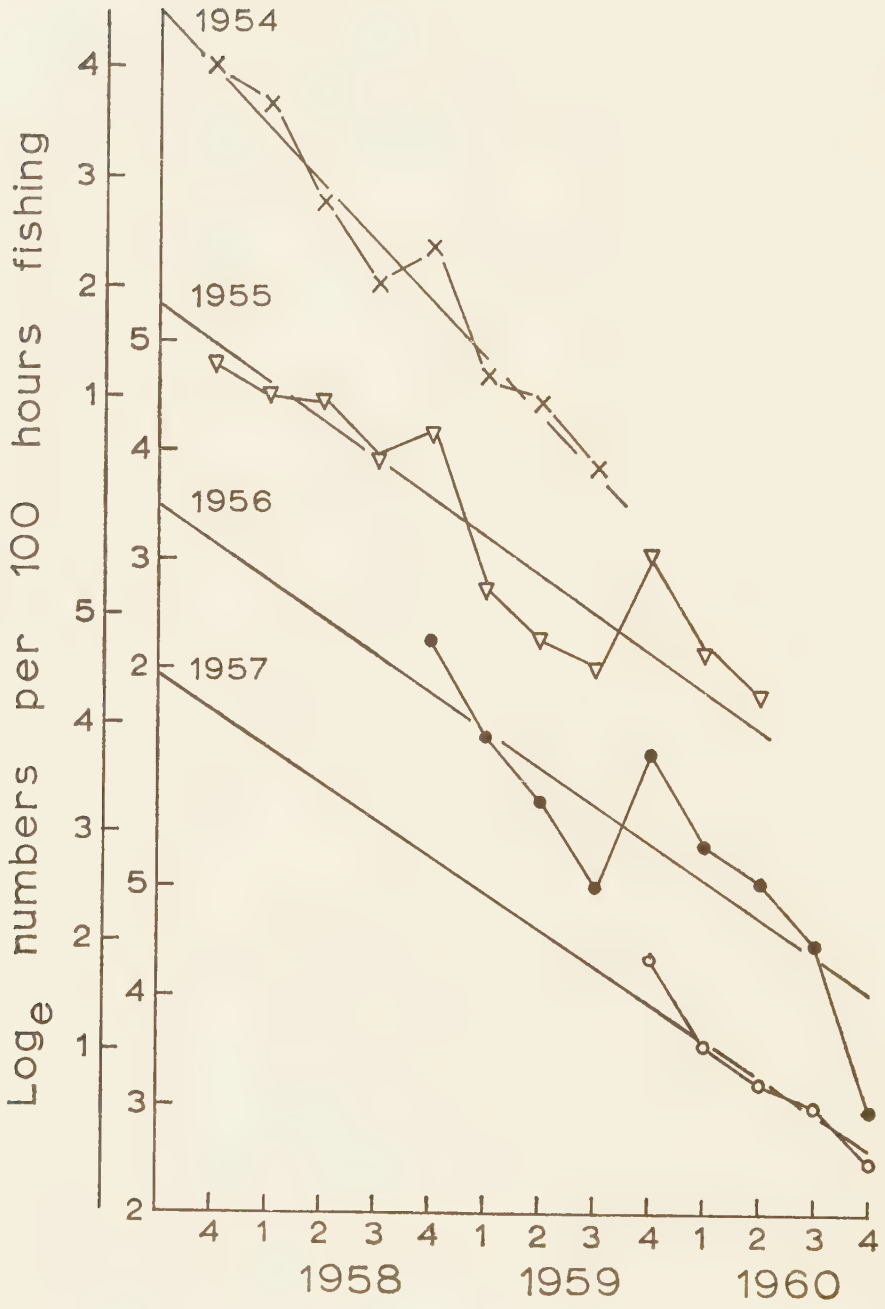

Fig. 4. A logarithmic plot of the declining abundance of the 1954, 1955, 1956 *and* 1957 *year-classes in the County Down whiting stock.*

1958 9 season. If 45% of these moved to other areas or suffered natural mortality, only twenty-eight could be expected to remain in the County Down area. Fourteen tags were returned during the second season, giving a 50% return which, within the obvious limits of the estimates available, suggests that emigrant whiting do not return to the County Down fishery.

THE SIGNIFICANCE OF RETURNS FROM OUTSIDE THE MARKING AREA

RECORDS are available of the total catch and fishing effort of English vessels fishing the statistical rectangles ZZ and A 5, 6, 7 and 8. These vessels also fish the County Down population, so that a value of q for whiting caught by English motor trawlers can be taken from the ratio of estimates of abundance of whiting recorded by the English motor trawlers and Northern Irish seiners. When the fishing effort is known, the coefficient qf can be applied to an estimated population of emigrant whiting in order to compare the expected number of recaptures by English vessels with the returns recorded.

This comparison between the expected and the actual number of returns provides a test of the accuracy of the foregoing analysis and is set out in detail in Tables 9 and 10, using the value q = 0·55% per 100 hours for Northern Irish seiners. In Table 9, Row A gives the effective fishing effort on the County Down stock by Northern Irish seiners. The product qf is given in Row B, with the monthly rates of (M + E) and (X M) in Rows C and D respectively. These coefficients are summed to give the monthly value of Z corresponding to (F + X + E) determined from the tagging results (Row E). Rows F (i) and G (i) give the numerical losses from the tagged population in the 1957-8 experiments, which are then distributed between the three factors comprising the total mortality, in Rows F (ii) and G (ii). The expected returns within the marking area (losses caused by fishing) can be

Table 9. *The distribution of the tagged whiting population in* 1957 8 (*q* 0·55% *per* 100 *hrs*)

	November	December	January	February	March	April
A. Hours fishing on tagged population	1,200	3,057 (2,000)	4,512	5,716	5,133	4,016
B. qf	0·069	0·184 (0·116)	0·285	0·377	0·332	0·250
C. M + E	0·143	0·420 (0·280)	0·420	0·420	0·420	0·420
D. X − M	0·140	0·430 (0·287)	0·430	0·430	0·430	0·430
E. Z	0·352	1·034 (0·683)	1·135	1·227	1·182	1·100
F. (i) Loss from $R_{(i)}$ (1634)	485	740	278	93	26	8
(ii) qf	95	131	70	29	7	2
(ii) M + E	197	301	103	32	9	3
(ii) X + E	193	308	105	32	10	3
(iii) Tags returned	83	97	89	13	18	20
G. (i) Loss from $R_{(ii)}$ (1527)		756	523	175	51	15
(ii) qf		135	131	54	14	3
(ii) M + E		307	194	60	18	6
(ii) X + E		314	198	61	19	6
(iii) Tags returned		161	121	36	13	16
H. Total natural losses (M + E), i.e. emigrants	197	608	297	92	27	9
I. H X (X + E)		128	479	505	388	270
J. Aggregate of emigrants	197	736	776	597	415	279
K. Adjusted for those present at beginning of next month		197	736	776	597	415

$R_{(i)}$ and $R_{(ii)}$ refer to the releases from Cruises XVIII and XIX, 1957 (15–27 November and 2 16 December, respectively); the parameters defining loss from the December experiment during the month of release are given in parentheses.

Table 10. *Comparison of expected with actual recaptures of tagged whiting by English vessels in Rectangles ZZ and A* 5, 6, 7, 8

	December	January	February	March	April	May	
A. Total emigrants (Row K of Table 9)	197	736	776	597	415	279	
B. Tags in rectangles stated (A × 0·588)	116	433	456	351	244	164	
C. Tags/rectangle (B/8)	14·5	54·1	57·0	43·9	30·5	20·5	
D. Total English effective effort (motor trawl hours)	2,764	4,274	3,755	9,000	7,192	6,112	
E. Hours/rectangle	346	534	469	1,125	899	764	
F. Expected % return (q = 0·092 %/100 hrs)	0·318	0·491	0·431	1·035	0·827	0·703	
G. Expected No./rectangle	0·04	0·26	0·25	0·45	0·25	0·14	
H. Total expected number	0·3	2·1	2·0	3·6	2·0	1·1	Σ=11
J. Actual returns			1	1	6	3	Σ=11

compared with the actual returns, which are shown in Rows F (iii) and G (iii). If it is assumed that the loss caused by natural mortality is negligible at this time (see above), Row H gives the number moving out each month, and Row I the numbers surviving from those that had moved out in previous months. These are still exposed to some small fishing mortality and, though this has been ignored, a correction has been made for the loss of (X M). In row J the survivors are added to 'newly arrived' emigrants, and in row K they are adjusted to the month in which they will become available for capture in other areas.

These emigrant whiting are carried over into Row A of Table 10. They may not all move into the Liverpool Bay area (i.e. Rectangles ZZ and A 5, 6 and 7 and 8), so they have been distributed in the ratio of recaptures in the Liverpool Bay area to the total recaptures outside the marking area (i.e. 40/68 = 0·588). The estimated number of tagged fish in Liverpool Bay is given in Row B and their density per rectangle in Row C. Similarly the total effective English effort in the area, in English motor trawl units, is given in Row D and distributed as the fishing intensity per rectangle in Row E. The estimated value of q is 0·168 / 0·55% per 100 hours 0·092% per 100 hours fishing by English motor trawlers. This, combined with the fishing intensity, gives the expected percentage recapture (Row F) which is then applied to the number of tags per rectangle (Row G). Summing the expected recaptures for the eight rectangles (Row H) gives the expected total tags recaptured by English vessels in Liverpool Bay for each month.

These tables show that considerable numbers of tagged whiting have left the marking area by January, but this is not to say that they should immediately become available to English fishermen in Liverpool Bay, or that the tagged fish are uniformly distributed over the area, although these assumptions have necessarily been made in estimating the expected number of returns. In fact the traditional whiting fishery off Conway (North Wales) does not set in until February. Hence the discrepancy in the distribution with time between the expected and actual returns by English fishermen in Table 10 (Rows H and J). However, the total numbers of returns for the December–May period are the same. Thus the value of q chosen as giving the most satisfactory explanation of changes in the County Down fishery also gives a quantity of emigrant whiting that is consistent with the number of tagged fish caught in Liverpool Bay. This supports the earlier conclusion that emigration from the County Down population may amount to 40% of the stock present at the beginning of each season.

SUMMARY AND CONCLUSIONS

(1) The results of three large-scale tagging experiments on the County Down winter seasonal whiting fishery have been analysed.
(2) Using the scale-damage classification at marking, an initial estimate of tagging mortality is used to determine the number of effective releases.
(3) The data are then analysed to estimate the catchability coefficient, q, and the monthly fishing rate, qf, in the County Down fishery.
(4) These data also give estimates of the total annual reduction coefficient, i.e. (F + X + E), which are combined with estimates of (F + M + E) from the commercial records to give estimates of basic parameters.
(5) Similar estimates are determined for limiting values of q to give a range of possible parameter values.
(6) By comparison with actual catch data the most probable combination of parameters is determined as F = 0·9 and (M + E) = 1·0 in 1957–8 and 1959–60. The estimate of (M + E) is almost entirely attributed to emigration. During the 1958–9 season emigration was very low: this is regarded as being atypical.
(7) The rate of emigration may amount to 40% of the original tagged population and will give sufficient numbers to account for the whiting recaptured outside the marking area.
(8) Analysis of the age composition shows that during the relevant period the total reduction in the County Down stock had the value (Z + E) = 1·4.
(9) It is concluded that during the season fishing mortality reaches the value F = 0·9 and other losses (mainly emigration) reach the level (M + E) = 1·0, giving a gross loss comparable to that reported in the Clyde whiting fishery. In the following season additional recruitment occurs, or there is a reversal of migration or availability of whiting in the same area, which reduces the value (Z + E) = 1·9 to a nett loss (Z + E) = 1·4, of which F = 0·9, natural mortality and emigration accounting for the remaining 0·5.

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Part III: The Clyde Whiting

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INTRODUCTION

WITHIN the Firth of Clyde there is an important demersal fishery during the winter months, carried on by Scottish vessels using the Danish seine-net. The development of this fishery since its beginning in the 1920s has been described by Ritchie (1960). The growth of the fishery was comparatively slow at first. After 1930 the local fleet of vessels became more numerous, and with a greater number of boats from the east coast of Scotland going to the Clyde each season, there was a considerable increase in the total landings. The main fishing port in the Clyde is now Ayr, and there are a number of vessels based on Campbeltown, and also a few working out of the other small Clyde ports.

Table 1. *Weights (cwt) of the principal species of fish landed in the Ayr district each year by seine-net vessels (from Scottish Sea Fisheries Statistical Tables)*

Year	Whiting	Cod	Haddock	Hake	Plaice	Saithe	Skate	Dogfish	Witches	Total Demersal
1954	30,539	12,648	11,818	6,441	2,517	986	1,538	1,124	1,291	70,426
1955	59,756	19,713	13,784	6,330	2,553	950	2,032	1,152	1,108	109,080
1956	16,158	26,671	9,569	4,333	3,503	1,025	1,906	1,224	928	67,262
1957	30,854	36,275	13,856	3,899	2,250	3,722	1,826	1,147	1,180	97,928
1958	52,487	39,314	20,660	1,266	2,802	3,128	2,106	2,549	1,331	129,312
1959	81,685	27,170	12,333	819	2,316	2,482	1,451	2,845	870	135,514
1960	30,727	17,397	7,131	1,901	2,701	3,450	1,506	2,790	594	70,659
1961	22,061	8,333	4,303	5,938	2,319	1,951	1,558	1,326	372	49,893

The most important single species in this Clyde seine-net fishery is the whiting. Its importance relative to the other kinds of fish landed can be gauged by the figures given in Table 1, which shows the weights of the main species landed by seine-net vessels in the Ayr district since 1954. Nearly all of these catches were taken in the Clyde area. Whiting averaged about 43% of the total landings over this period, but the actual weight and proportion of whiting landed varied considerably from year to year. The whiting landings were very poor in 1956, when they were exceeded by the quantity of cod landed, and this also occurred in 1957. The whiting landings were good in 1959, when the total weight of demersal fish landed was also at its highest level for the eight years covered by the data.

A certain amount of fishing is also carried on in the area by foreign vessels, mainly French trawlers, but they appear only irregularly on the grounds. The total size of their catches is not known, but is thought to be relatively small.

STRUCTURE OF THE WHITING FISHERY

SEASONAL FLUCTUATIONS IN THE LANDINGS

Since the Clyde whiting fishery is a winter one, the annual figures given in Table 1 combine the landings from the second part of one winter's fishery with those from the first part of the next. Therefore they do not give a very accurate indication of the success of each separate season. To overcome this difficulty the monthly landings of whiting per unit of fishing effort by seine-net vessels working in the Clyde have been plotted in Figure 1. This demonstrates that the season extends, on average, from October to April, and also indicates the duration of the fishery each winter.

The 1954–5 season was a good one, but the next two winter seasons were poor, particularly that of 1956–7. The landings improved in 1957–8 and the 1958–9 season was also good, but both the 1959–60 and the 1960–1 seasons were relatively poor, lasting only a short time in spite of the high level of landings at the peak of each winter's fishing. The 1961–2 landings also rose to a very high level for a short time, but did not fall away so rapidly in the spring as in the two previous seasons.

MARKET SAMPLING

The whiting landings from the Clyde have been investigated by a programme of market sampling which was started in 1959. This was carried out at Ayr, and provided good coverage of the whole whiting fishery conducted in the Clyde.

The whiting landed are generally sorted into two size categories, large and small. Initially, the landing by one vessel was sampled each week, and this sample consisted of a box, containing 7 stones of fish, from each category. These whiting were measured and otoliths were taken for age-determination. From the beginning of 1961 it became possible to increase the sampling programme during the winter fishery. This enabled the landings from more vessels to be measured, although the number of otolithed samples for constructing the age/length keys used to work up these measurements remained the same.

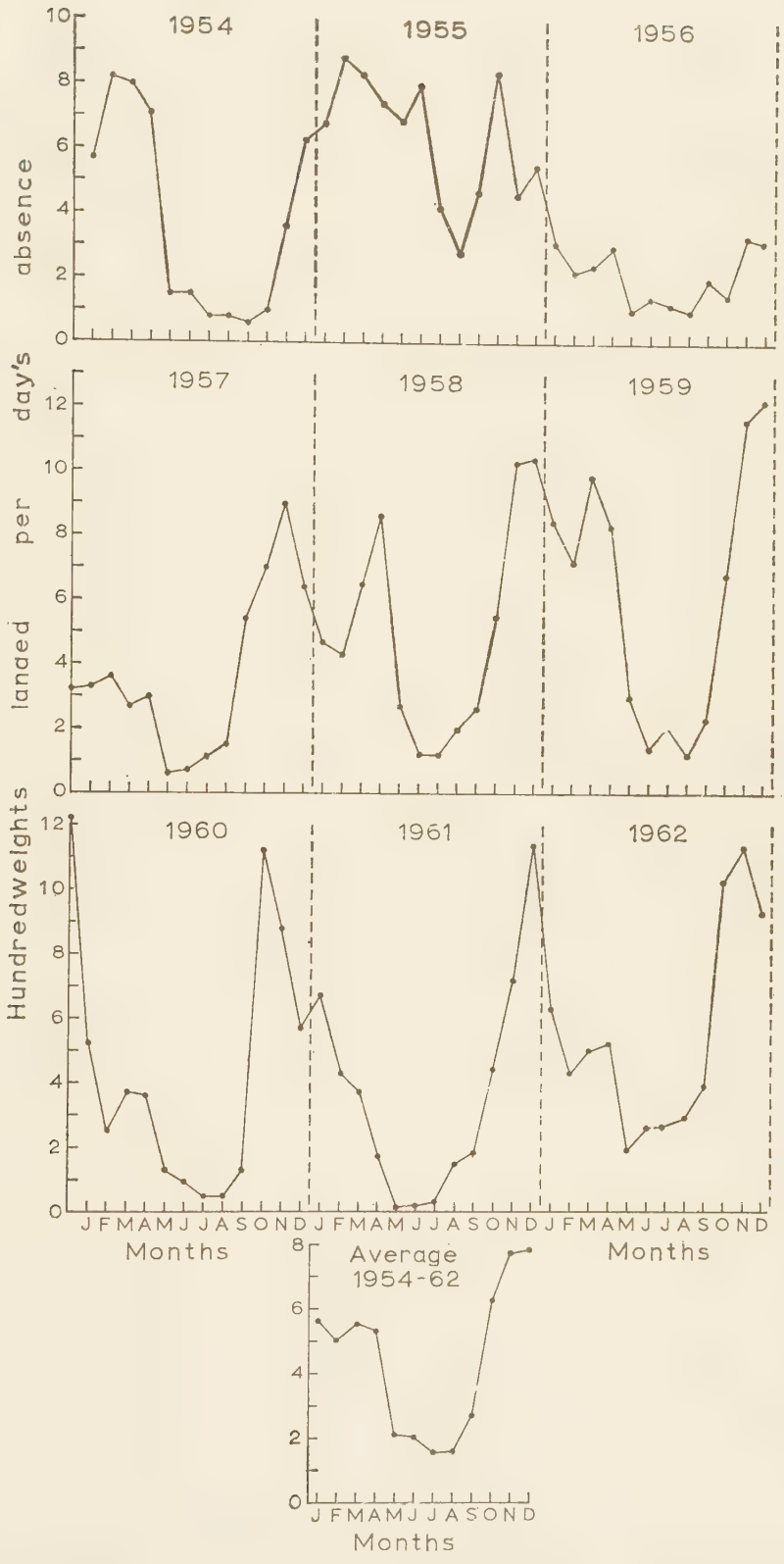
The data collected in the sampling programme make it possible to follow the seasonal and annual changes in the size- and age-compositions of the landings and to determine the major causes of the fluctuations which occur in the fishery.

AGE-COMPOSITION OF THE LANDINGS

The age-compositions of the whiting landings from the Clyde for the period 1959 to 1962 are illustrated by the monthly histograms given in Figure 2. These show that the winter fishery each year is almost entirely dependent on a single year-class of whiting, between one-and-a-half and two years old.

The whiting landings at the beginning of 1959 consisted largely of the 1957 year-class. The catches of this year-class declined towards the summer, and in October the 1958 year-class replaced it as the main component of the landings. These fish, which were then about 18 months old, sustained the fishery into the following year, but the landings fell to a low level early in the spring of 1960, and the fishery did not last as long as in the previous year. The new recruit year-class (1959) came in strongly in October 1960, but again did not continue very long into the following spring. The winter fishery at the end of 1961 also built up well, based on the 1960 year-class, and this year-class was relatively abundant until the following April. The 1961 year-class was very prominent in the landings at the end of 1962.

It is clear that, since the landings have this age-structure, the success or failure of the whiting fishery in the Clyde is largely determined by the strength of a single year-class each winter. Each year-class has its major effect on the fishery for only one season, and then,


1954
1955
1956
1957
1958
1959
1960
1961
1962
Hundredweights landed per day's absence
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Months
Average 1954-62
J F M A M J J A S O N D
Months

Fig. 1. *Monthly landings of whiting per day's absence by seine-net vessels fishing in the Clyde.*

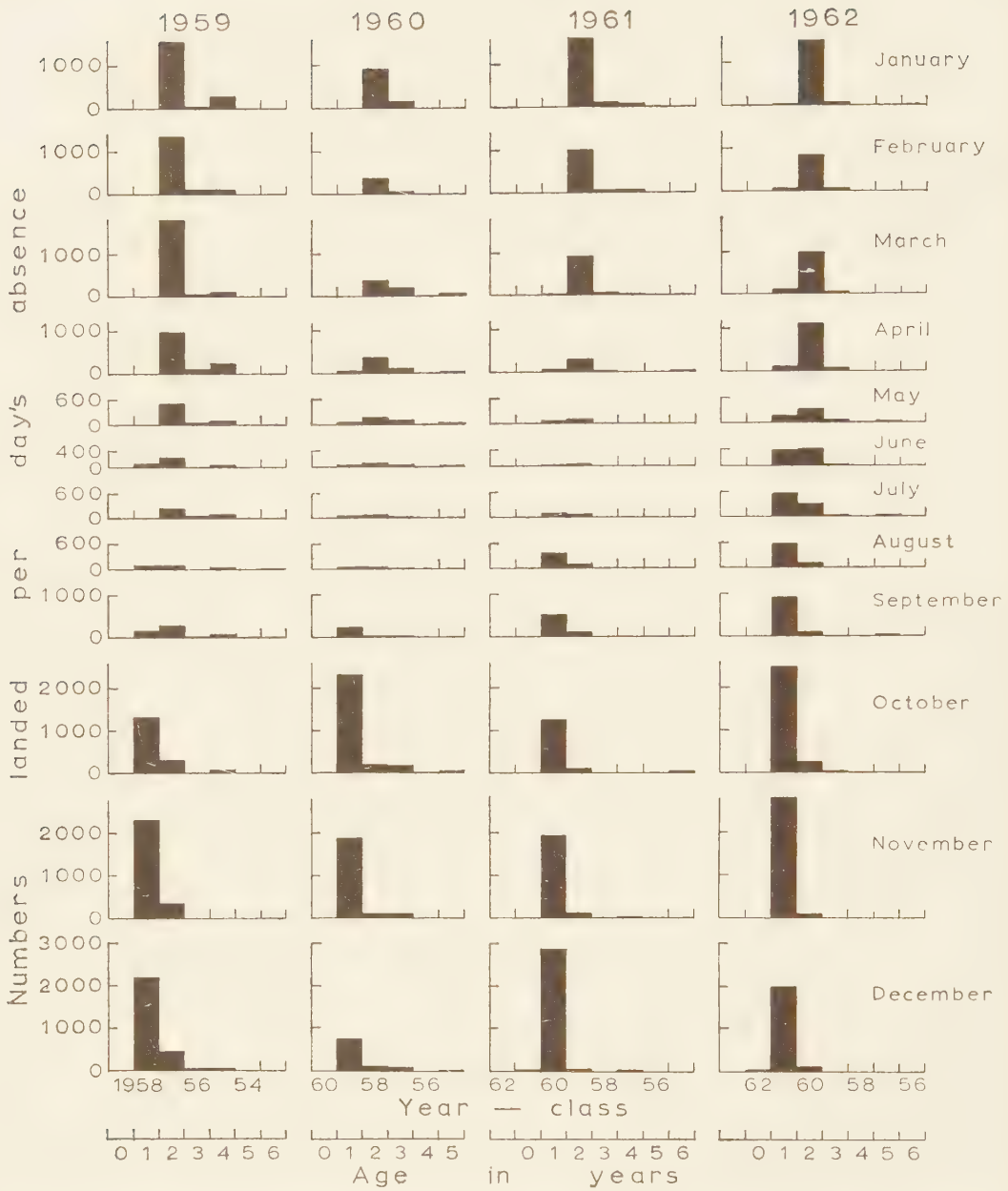

Fig. 2. *The numbers of whiting of each year-class landed per day's absence from the Clyde by seine-net vessels.*

because there are so few older fish present in the landings, it plays a very minor part in the following years. The variations between the sizes of the fishery in one season and the next are thus dependent upon the strengths of the successive recruit year-classes, and it is the entry of these whiting into the fishery which causes the rapid increase in the landings at the start of each season.

LENGTH-COMPOSITION OF THE LANDINGS

The length-composition of the whiting landings from the Clyde are illustrated in Figure 3 by the representative monthly length-frequency curves for the four sampling years. The size-

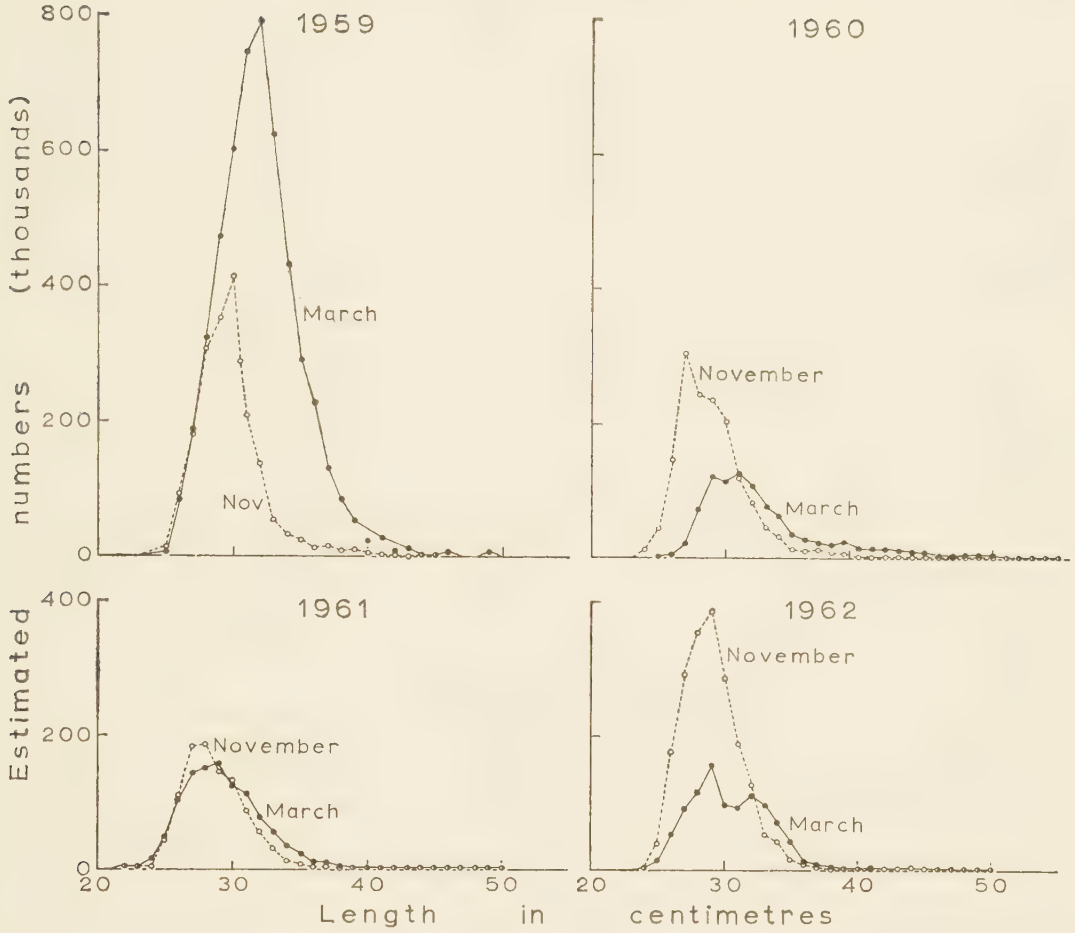

Fig. 3. *Monthly length-compositions of whiting landings from the Clyde by seine-net vessels (estimated total numbers landed).*

compositions are similar in each year. At the start of the winter fishery each season there is a predominance of small whiting (between 25 and 30 cm) in the landings, representing the new recruit year-class. As the season progresses, and as the fish grow, the proportion of larger whiting landed increases and the mean length of the landings also rises.

THE CLYDE WHITING STOCK

LENGTH- AND AGE-COMPOSITIONS OF THE TOTAL WHITING STOCK

The length-compositions are available of whiting catches taken by research vessels trawling on the main fishing grounds in the lower reaches of the Clyde. Those from hauls in which the cod-ends had been fitted with small-meshed covers, including the fish which are too small to be taken by the commercial vessels, are shown in Figure 4. No direct comparison between the numbers of whiting caught in the different months is possible, as conversion factors for the three research vessels involved and the various trawling gears used are not known. The data have therefore been expressed in percentage units.

These research vessel catches show that the youngest (O-group) whiting are found in the Clyde together with the larger, commercially exploited fish. They are taken in the small-

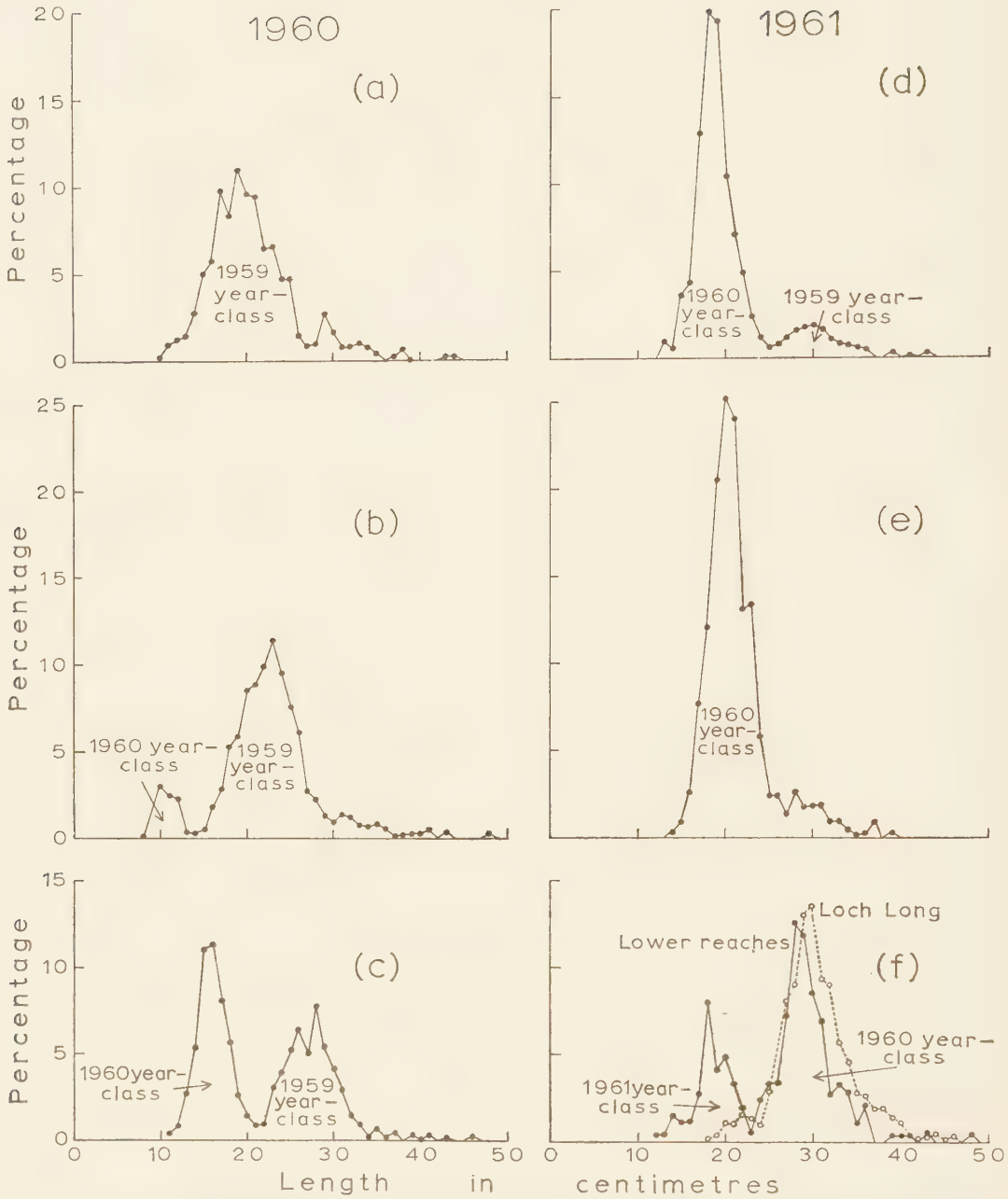

Fig. 4. *Length-compositions of research vessel catches of whiting in the Clyde (small-meshed cover fitted to cod-end).* (a) *May* 1960; *F.R.S.* SCOTIA, *wing trawl.* (b) *July* 1960; *F.R.S.* SCOTIA, *otter trawl.* (c) *November* 1960; *F.R.S.* MARA, *wing trawl.* (d) *March* 1961; *F.R.S.* EXPLORER, *otter trawl.* (e) *May* 1961; *F.R.S.* SCOTIA, *otter trawl.* (f) *November* 1961; *F.R.S.* MARA, *wing trawl.*

meshed cover from July onwards, which is about the time when they begin to go down to the bottom after their pelagic larval and post-larval stages. The whiting are therefore present in the Clyde from the start of their demersal phase. Comparison of Figures 3 and 4 indicates that the age-composition of the research vessel catches differs from that of the commercial landings only by the addition of this youngest age group.

An interesting feature of the whiting stock in the Clyde is the slightly different size-compositions of the fish in the lower reaches and those in the upper part of the Firth. This is illustrated in Figure 4 (f) by the length-composition of the catches taken in November 1961, in both the lower reaches and Loch Long, which lies at the head of the Firth. The catch in Loch Long had very few of the 1961 year-class (O-group) of whiting which were found lower down the Clyde, and the fish of the 1960 year-class caught there tended to be slightly larger on average. This rather bigger overall size-composition is a general characteristic of the catches taken at different times in Loch Long.

It is convenient at this point to compare the Clyde whiting stock with the whiting populations off the western and northern coasts of Scotland. These latter have been

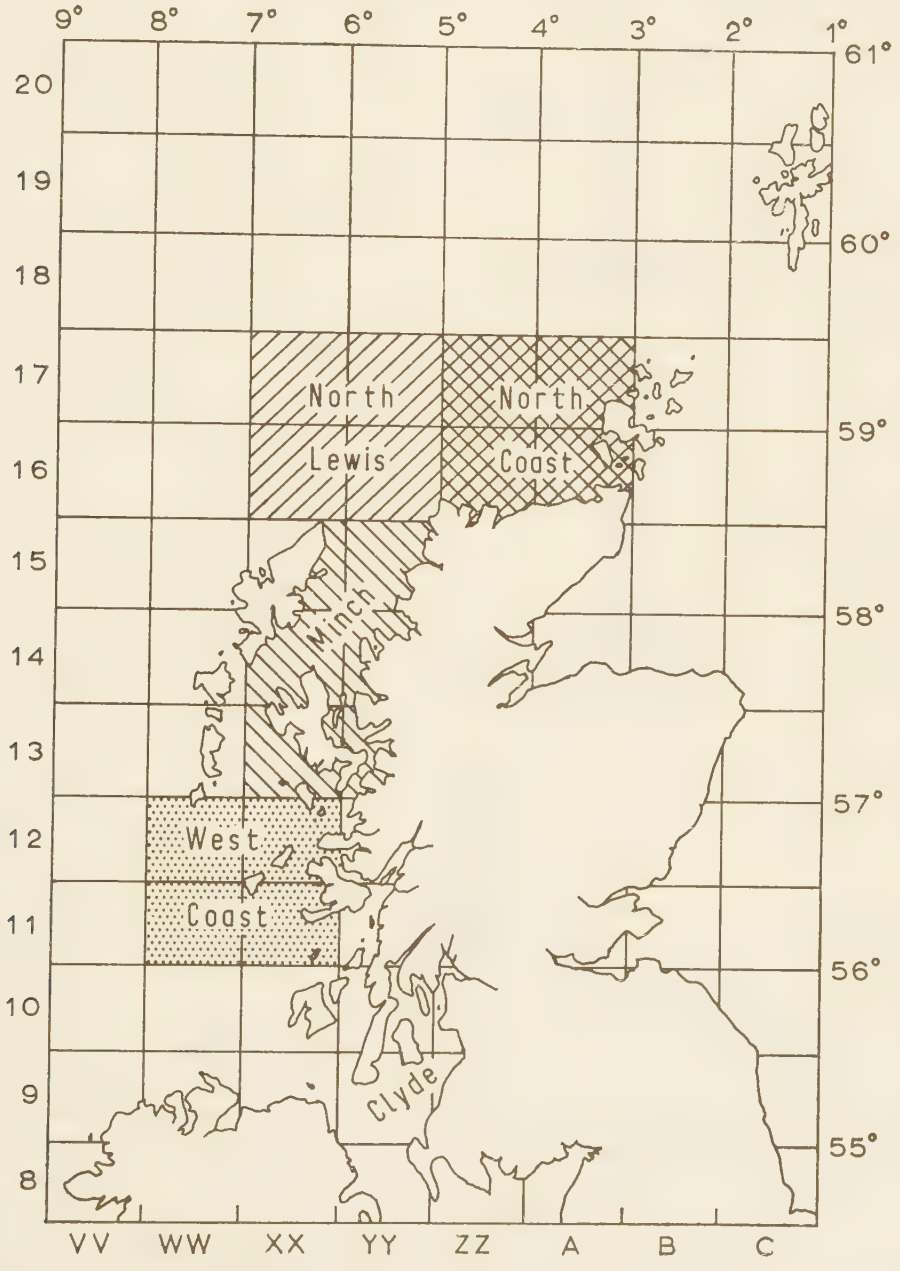

Fig. 5. *Scottish west and north coast sampling areas.*

investigated by market sampling and by research vessel trawling, and although the length-compositions of the catches are similar to the length-composition in the Clyde (Gambell 1960), the age-compositions differ considerably.

The Scottish west and north coast areas sampled by research vessels using small-meshed covered cod-ends on the trawl are shown in Figure 5. These are based on the local fishing grounds, and the average age-compositions of the catches taken in each area in November 1959–62 are illustrated in Figure 6. Averaging the data over this period of time smoothes out the year-class variations which occur, and provides an idealized structure of the catches. The North Coast, North Lewis, Minch and West Coast areas all have very similar age-structures, in which the 1-year-old whiting predominate. This contrasts with the composition in the Clyde picture, where the O-group fish are most abundant.

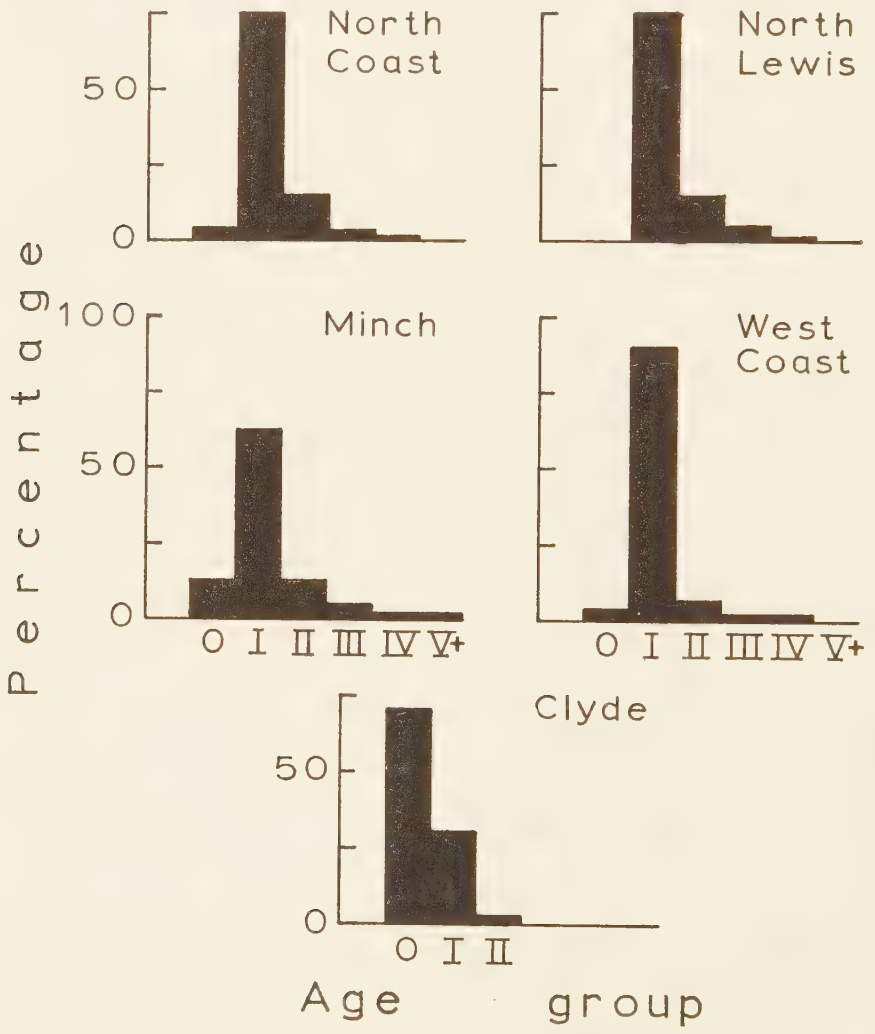

Fig. 6. *Average percentage age-composition of whiting caught by F.R.S.* EXPLORER *on Scottish west and north coast grounds (small-meshed cover fitted to cod-end).*

GROWTH

The mean lengths of the Clyde whiting at different ages have been calculated, using all the available market sampling and research vessel data. The sexes have not been differentiated,

since the market samples were gutted and the males and females could not be distinguished. The mean lengths are plotted in Figure 7 and the growth curve shown was drawn in by eye. Part of the scatter for the older ages is probably due to differences in the growth of male and female fish, as research vessel samples show that the females are larger at each age than the males, as has been found for all other whiting stocks investigated (see Garrod, Part I of this publication).

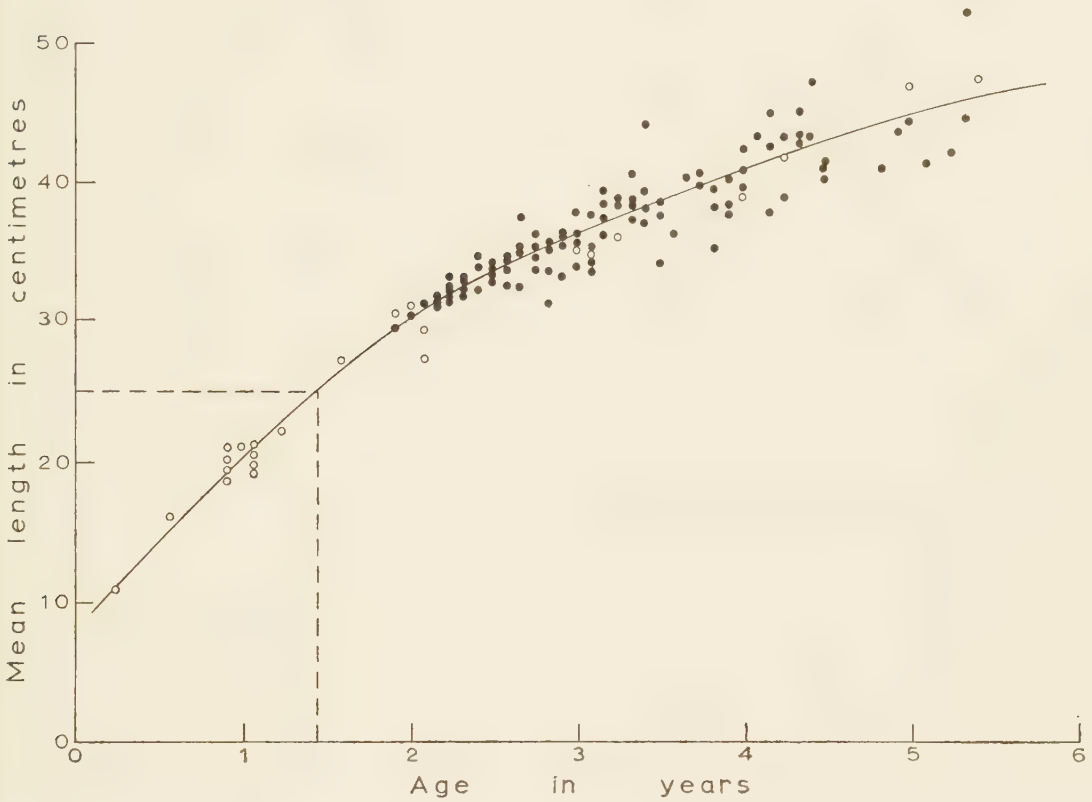

Fig. 7. *Mean lengths of Clyde whiting, from market sampling data (solid circles) and research vessel data (open circles).*

The age at which the whiting enter the fishery can be read from the growth curve as the time when the fish reach 25 cm in length. This point falls between the September and the October of their second year of life, when they are about 18 months old, and it agrees well with the age-composition data of the commercial landings already given.

The growth curve for whiting off the west coast of Scotland has also been derived, from research vessel data. No differences were observed between the mean lengths for each age over the whole region from the North Coast area to the West Coast area (see Figure 5), and therefore the data from all four areas were pooled to obtain the west coast curve plotted in Figure 8. This illustration also shows, for comparison, the growth curve of Clyde whiting calculated from derived parameters (see below) and that of North Sea whiting given by Ellis and Jones (1956). The observed growth of Irish Sea whiting up to four years of age is also included, but beyond this age the mean lengths of fish could not be reliably determined from the work reported in Part I of this publication (Garrod, pers. com.).

The parameters for the von Bertalanffy growth equation have been calculated for the growth curve shown in Figure 7, using the methods described by Beverton and Holt (1957).

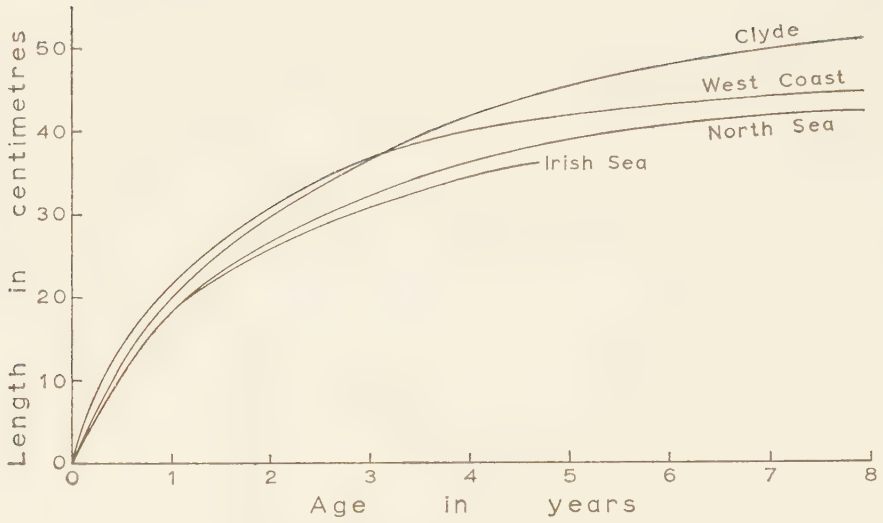

Fig. 8. *Whiting growth curves.*

These values are compared with parameters calculated for the growth of west coast whiting and those given by Ellis and Jones for North Sea whiting.

	Clyde	West Coast	North Sea
L_∞ (cm)	54·5	45·0	44·2
K	0·322	0·483	0·383
t_0 (yr)	−0·48	−0·42	−0·44

It may be seen from Figure 8 that the mean length at each age of Clyde whiting is greater than in the North Sea and also, after the third year of life, than on the west coast grounds. The Clyde whiting growth rate is also greater than that of the Irish Sea whiting, which are the slowest-growing of these four groups, but Garrod has pointed out (see Part I) that this may represent a minimum estimate of growth owing to the movement into deeper water of the faster-growing fish, which were therefore not sampled.

MOVEMENT

Tagging experiments have been carried out, in November 1960 and 1961, in order to trace the movements of the Clyde whiting. All the fish tagged were of marketable size, that is 25 cm or bigger. The majority belonged to the I+ age-group, but there were also a few older individuals.

Whiting were marked and liberated in the open reach of the estuary during the experiment in 1960. Until the beginning of March 1961, which was roughly 100 days after release, all the returns came from the main fishing grounds within the Clyde area (Figure 9). After this time, which coincided with the close of the winter fishery (see Figure 1), a number of recaptures were made outside the Clyde. Two were in the Irish Sea, two in Donegal Bay on the west coast of Ireland, and one in the Tiree area of the South Minch. These are shown in Figure 10, together with some further recaptures from the Clyde itself, including one whiting caught more than a year after being tagged.

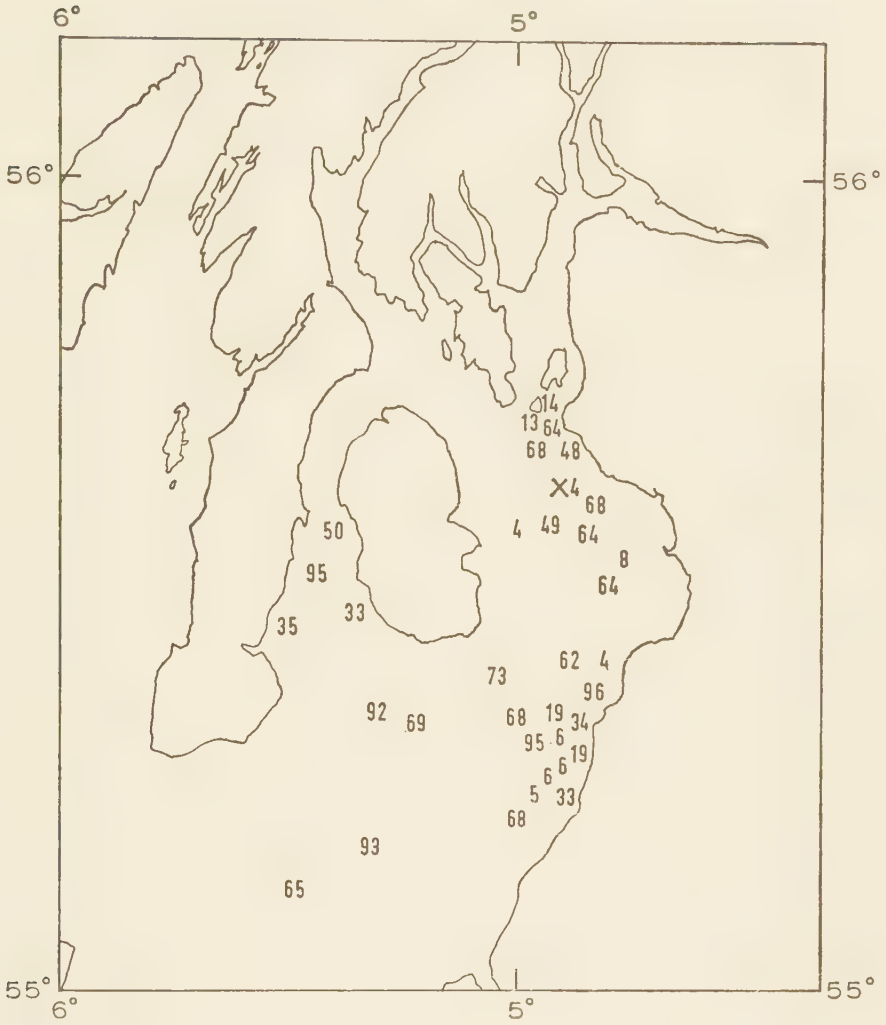

Fig. 9. *Recaptures of tagged whiting up to* 100 *days after release from the November* 1960 *experiment (plotted as number of days free). The liberation area is indicated by a cross.*

The tagging programme in November 1961 was carried out in Loch Long, much further up the Clyde than the ground worked the previous year. The returns from this experiment are shown in Figure 11. The initial recaptures came from the immediate area of tagging, but later ones tended to be from points progressively further and further down the Clyde. Returns after 100 days, roughly from March onwards, again showed a widespread distribution in the open reaches of the Clyde and outside, with two whiting recaught in the Irish Sea and one in the Tiree area.

The impression from the tag returns is of a general mixing of the stock in the Clyde area during the period of the winter fishery. After March there is a more widespread distribution, with whiting moving to the outer reaches of the Clyde and beyond. The timing of this movement suggests that it might be connected with spawning behaviour, the whiting stock migrating in the spring to the spawning grounds, and afterwards dispersing over a wide area, with relatively few fish returning to the Clyde.

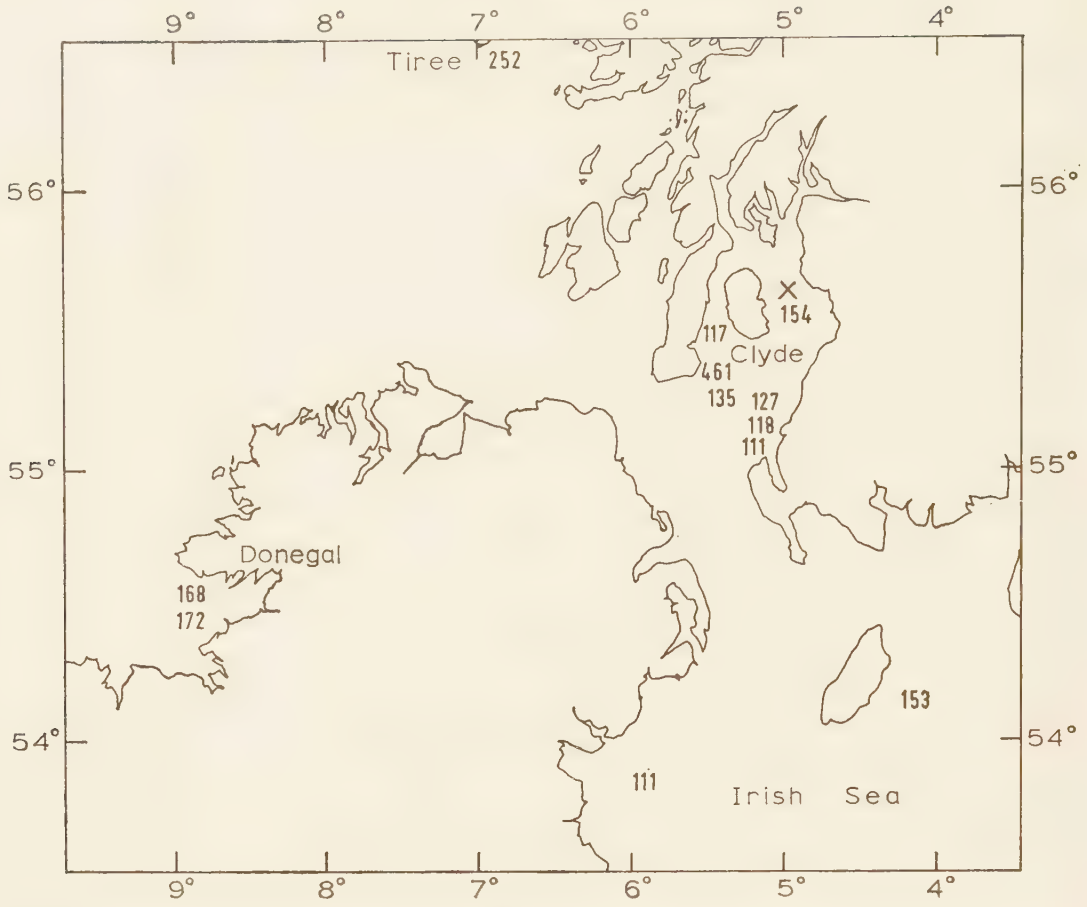

Fig. 10. *Recaptures of tagged whiting made more than* 100 *days after release from the November* 1960 *experiment (plotted as number of days free). The liberation area is indicated by a cross.*

LARVAL DISTRIBUTION

Although the commercially exploited whiting stock contains a high proportion of fish with ripening gonads immediately before the spring-spawning period, there is no large-scale fishery on a spawning population, since the density of whiting appears to decrease rapidly just at the spawning season (Figure 1). Nor is there a fishery based on spawning whiting on the fishing grounds adjacent to the Clyde area (see Garrod, Part I of this publication); hence the location of the spawning grounds of the Clyde whiting stock has had to be based on investigations into the distribution of whiting larvae.

Plankton samples, which had been taken primarily to study the distribution of herring larvae in the Clyde area, were available, and these were examined for whiting larvae. The samples had been obtained by oblique hauls from bottom to surface with a 1-metre silk net of 60 threads per inch. The distributions of the whiting larvae in May 1960 and 1961 are shown in Figures 12 and 13, where the numbers taken, converted to a standard towing time of 15 minutes, are plotted.

The main features of the distributions in both years are the relative concentrations of whiting larvae along the coast of Northern Ireland immediately opposite the mouth of the Clyde, and the small numbers of larvae found in the greater part of the Clyde itself. This suggests that the main spawning area is outside the Clyde, so that the spawning products must drift into the Clyde to regenerate the stock there each year.

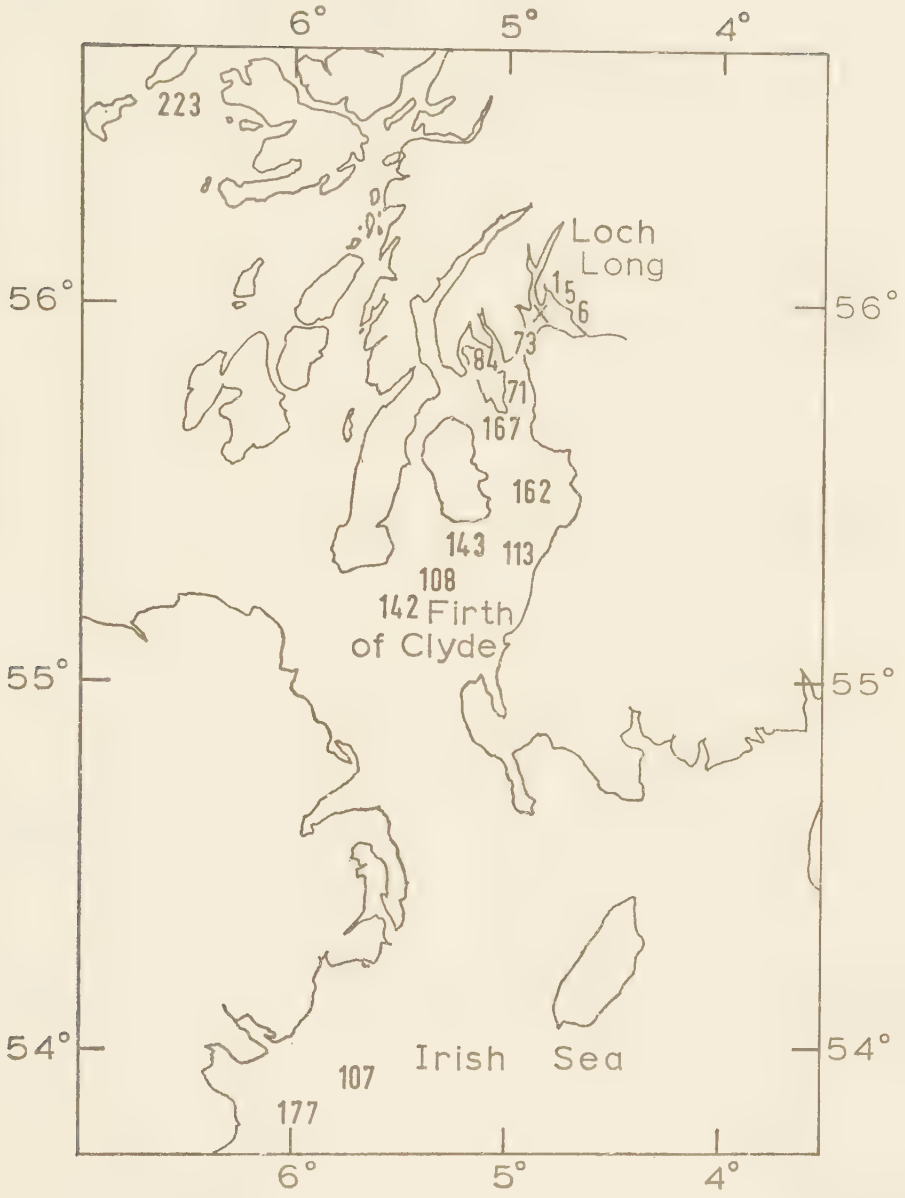

Fig. 11. *Tagged whiting returns from the November* 1961 *experiment (plotted as number of days free). The liberation area is indicated by a cross.*

To attempt to define spawning area by means of the larval concentrations is obviously not the best technique to choose – the eggs and larvae can drift some distance between the spawning period and the time of sampling – but in the absence of better and more direct evidence, some indication of the spawning centres can be gained by this method.

ASSESSMENTS OF THE STOCK

TOTAL MORTALITY

The age-composition data collected during the market sampling programme can be used to calculate the apparent total mortality coefficient (Z) for the Clyde whiting stock. When this

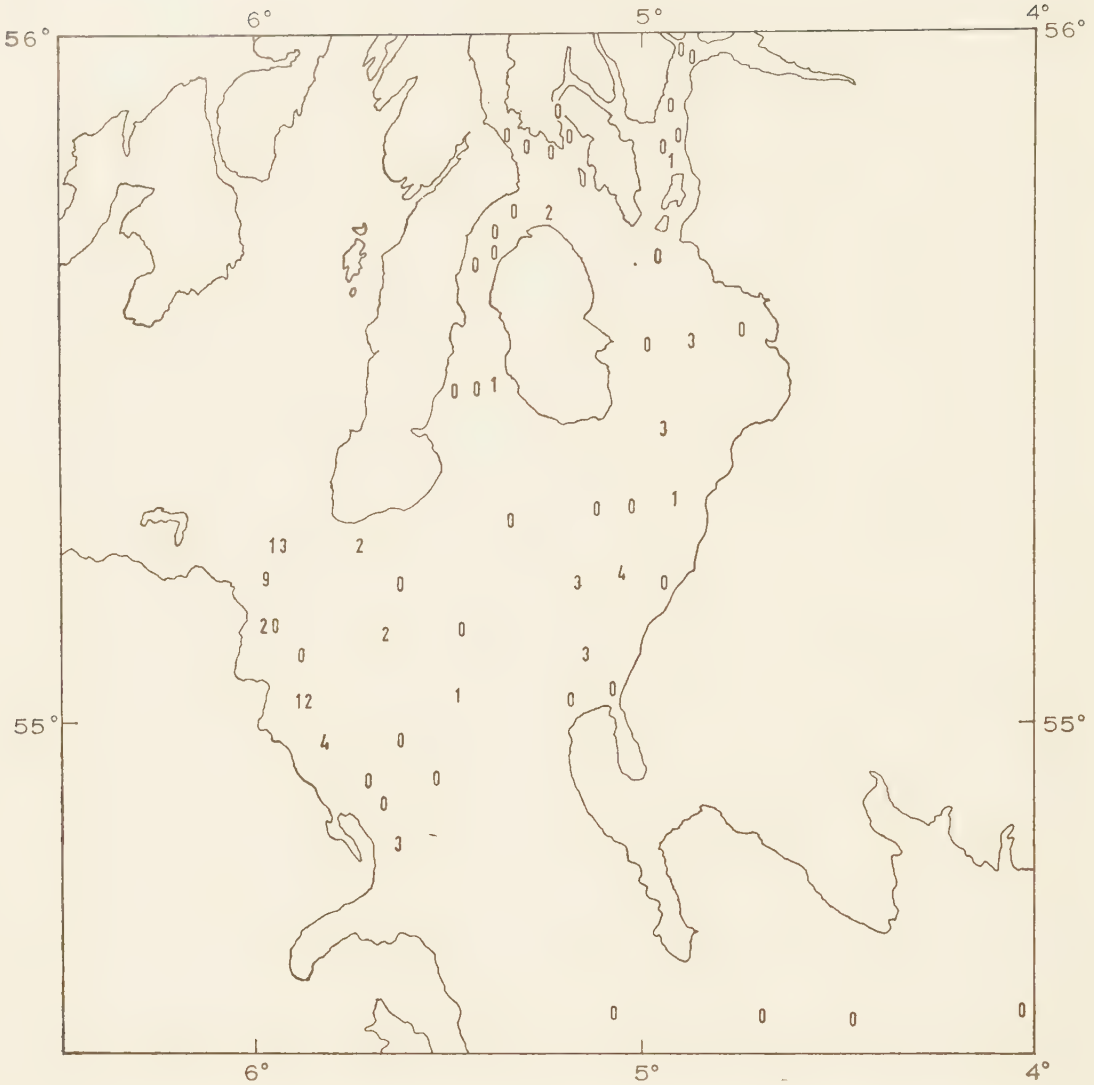

Fig. 12. *Numbers of whiting larvae taken in* 15-*min. oblique plankton hauls. May* 1960.

is done for all of the year-classes fully recruited to the fishery in the period investigated, a very high mean value of Z = 2·21 is obtained, which represents an annual reduction in the whiting stock of about 89%. This is a little greater than the initial loss from the County Down fishery (Garrod, Part I of this publication). The values of Z for the Clyde fishery for different ages and sampling years are shown in Table 2. Because the data are limited to only four years' sampling, any conclusions drawn from them can only be tentative. There is no statistically significant difference between the values of Z for the 2 3 and 3–4 years age groups in 1959–60 and 1961–2, but they do differ significantly from the estimates for the same age groups over the 1960–1 period. The total mortality rate in 1960–1 appeared to be very high. The numbers of whiting aged four years and more are small compared with the numbers of the younger age groups, so that the mortality estimates for the older fish are much less reliable. Although the values of Z between ages 4 and 5 are significantly smaller than those for the younger ages in 1960–1 and 1961–2, they are not different for the 1959–60 period. It is not clear whether these older fish do have a lower apparent mortality rate than the younger ones, or if the varying results are due to the relatively small numbers of whiting concerned.

Fig. 13. *Numbers of whiting larvae taken in* 15-*min. oblique plankton hauls. May* 1961.

There are two possible causes for this very high apparent total mortality rate for the Clyde whiting stock, and these may be acting together. Either the fishing mortality may be very heavy, or, alternatively, there may be a high apparent natural mortality rate, including the emigration of part of the stock out of the area. The investigation of the factors contributing to the total mortality is discussed below.

Table 2. *Estimated values of Z for Clyde whiting*

Age (years) \ Period	1959–60	1960–1	1961–2
2–3	2·01	3·81	1·99
3–4	2·04	3·54	1·95
4–5	1·91	1·98	0·96
5–6	—	2·69	
Average	1·99	3·00	1·63

ANALYSIS OF MORTALITY

It was noted in the introduction that the seine-net fishery in the Clyde started in the 1920s. The fishery developed slowly at first, but now it is a very intensive one in the winter season. If the fishing mortality is responsible for a very large part of the apparent total mortality of whiting in the area, changes in the length-composition of the exploited stock would be expected between the present time, with its high fishing effort, and the 1920s, with a much lower effort.

The length-compositions of some research vessel trawl hauls made in the Clyde from 1927 to 1930 are available, and those for which small-meshed covers were used on the cod-end have been compared with the length-frequency data from more recent years. It appears that the length-compositions of the stock in both periods were very similar. This is illustrated in Figure 14, where the average length-compositions of catches made by the old F.R.S. *EXPLORER* in August and September 1927 to 1930 are plotted together with the average catches taken by F.R.S. *MARA* in November 1960 and 1961 (derived from Figure 4). Direct comparison of the catches in the two periods is difficult, because the sampling was not carried out at exactly the same time each year, but it is clear that there has been little, if any, reduction in the relative numbers of big fish in the Clyde since 1927–30. This suggests that the fishing mortality is not the most important component of the apparent total mortality observed.

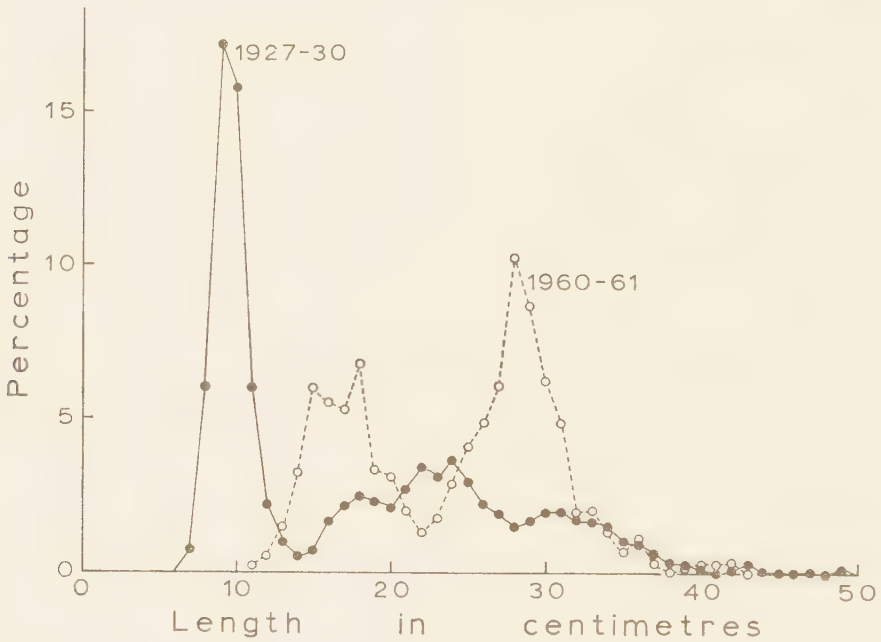

Fig. 14. *Length-compositions of research vessel catches of Clyde whiting* (*F.R.S.* EXPLORER, *August–September* 1927–30; *F.R.S.* MARA, *November* 1960 *and* 1961).

Unfortunately it has not been possible to obtain reliable estimates of F, the fishing mortality, from other sources. The data from the two tagging experiments in 1960 and 1961 have been analysed in order to arrive at a value, but as they give widely varying estimates of F = 0·23 and 0·57 respectively they are not thought to be very accurate. These results are based on the returns from the Clyde area during the twelve months from the time of tagging. In calculating the values of F, allowance has been made for the known return rate of only 50% of tagged fish by merchants after the landings have left the markets. The percentage of tagged fish which is found by the fishermen is not known, however.

All the whiting tagged in these experiments were graded as in good scale condition, according to the Lowestoft classification (Beverton, Gulland and Margetts 1959). These authors consider that the mortality at tagging of even these fish may be around 50%, so that the present estimates for the Clyde are likely to be too small by a factor of at least two. This means that better values from these experiments would probably be F = 0·46 and 1·14. Comparing these with the apparent total mortality rate of Z 2·21 suggests that the fishing mortality may contribute up to half of the apparent total mortality, but this still leaves a large coefficient attributable to another cause, such as emigration, together with natural mortality. This would be in line with Garrod's findings for the County Down fishery (see Part II of this publication).

WEIGHT/LENGTH RELATIONSHIP FOR GUTTED CLYDE WHITING

Weekly samples of 50 whiting were measured and weighed during 1959 and 1960. From these data the average annual relationship between gutted weight and length of fish was plotted (Figure 15). With a logarithmic scale on both axes the points fall very nearly in a straight line, and this line is close to the line obtained for gutted northern North Sea whiting (Gambell 1963). The gutted Clyde whiting over 35 cm in length are about 2% heavier than those from the northern North Sea, but fish of less than this size are the same weight as their North Sea counterparts.

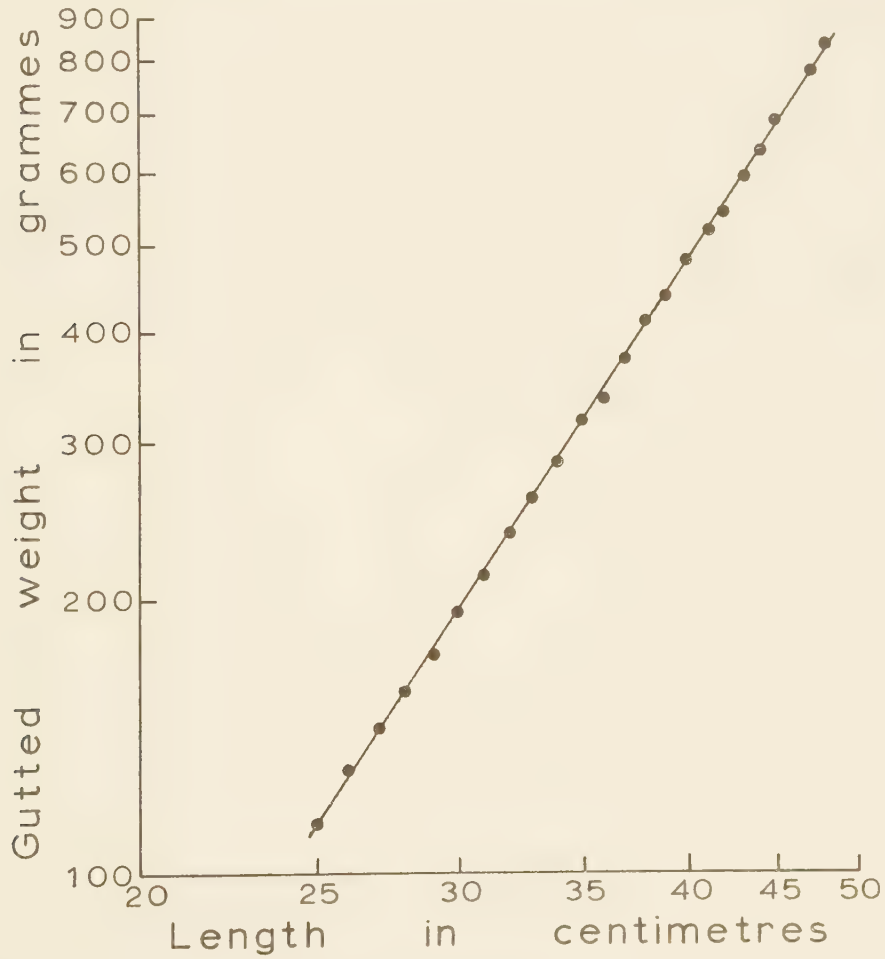

Fig. 15. *The weight/length relationship for gutted Clyde whiting.*

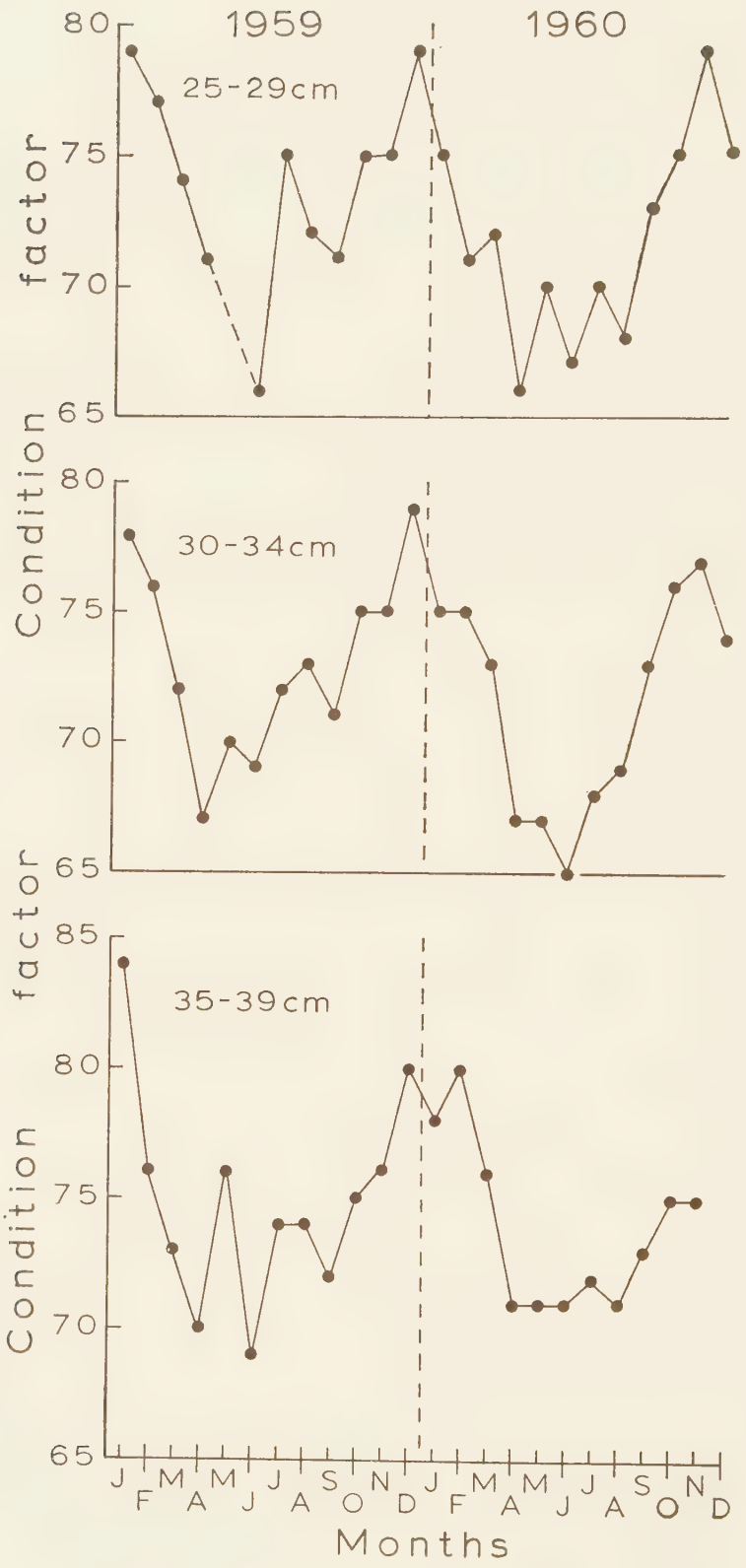

Fig. 16. *Condition factor of gutted Clyde whiting.*

CONDITION FACTOR OF GUTTED CLYDE WHITING

The condition factor (k) from the formula $k = 100\ g/l^3$, where g is the gutted weight in grammes of a fish 1 cm in length, was calculated for each centimetre-length each month. Because the value of k tends to increase with size of fish (Messtorff 1959, Gambell 1963), the mean values for three size-ranges are plotted in Figure 16, which demonstrates the seasonal fluctuations that occur in the relationship. The maximum values occur in winter (between November and February), and the minima in spring (April–June). These lowest values are obtained at about the same time as the minimal figures in the northern North Sea (Gambell 1963), but the peak values are later in the Clyde than in the northern North Sea, where they occur in August-September each year.

SUMMARY

THE Scottish seine-net fishery for whiting in the Clyde is a winter one, extending from October to April. Analysis of market sampling data shows that in each year the fishery is almost wholly dependent on a single year-class of whiting, between one-and-a-half and two years old.

Research vessel catches indicate that whiting are present in the Clyde from the beginning of the bottom-living phase of life. Growth is rapid and the whiting enter the fishery at the age of eighteen months, just as they are becoming sexually mature. The results from tagging experiments suggest that there is a general mixing of the stock during the time of the winter fishery. At the spring spawning period the stock appears to move towards the open reaches of the Clyde and beyond. Whiting larvae have been found in the area opposite the mouth of the Clyde, and this is probably the spawning ground.

Very few older whiting appear in the fishery, and it is likely that a large part of this seasonal reduction in the stock is the result of emigration, and that not more than half is due to fishing mortality.

The weight/length relationship and the condition factor for gutted Clyde whiting are also derived.

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Part IV: Some comparisons of the Irish Sea and Clyde whiting populations

R. GAMBELL and D. J. GARROD

THE descriptions of the whiting fisheries given in Parts I and III of this publication have drawn attention to a number of striking similarities which exist between the County Down whiting in the Irish Sea and the Clyde whiting populations.

These both support seasonal fisheries during the autumn and winter months, and in both areas the course of the season may vary from year to year. For example, in the 1958–9 season the fishing in the second half (January–March) was especially good in both fisheries, but in other seasons (e.g. 1959–60) catches after the new year have been relatively small.

The fisheries depend for their catches upon the youngest year-class of whiting to reach fishable size. These fish are present in both localities from the time they adopt the demersal habit in the summer of their first year of life, but they are not sufficiently large to provide commercially catchable concentrations until they are eighteen months old, in October of their second year. At this time the Clyde whiting are considerably larger than the County Down whiting, owing to a regional difference in growth rate (see Part III, Figure 8).

Within the Irish Sea area there is a difference in the age-compositions of the populations on the County Down and Rockabill grounds (consisting largely of O- and I-group immature whiting, as in the Clyde) and the populations on the Whitehaven and Conway grounds. These latter consist of older, adult whiting, as does the whiting stock along the Scottish west and north coasts. The only major spawning area which has been revealed by these investigations is shown in Figures 12 and 13 of Part III, but this area is not suitable for bottom trawling or seining, and so its precise boundaries have not been established; however, the general location is believed to lie between the northern limit of the County Down fishery and the southern limit of the Clyde fishery.

Detailed studies of the Clyde and County Down populations have shown that both suffer a seasonal loss from the stock amounting to 85–89%, and in each case only half of this value can be reliably attributed to fishing. Comparison of recent length-compositions in the Clyde with those for years before heavy exploitation developed, and analysis of English tagging results in the Irish Sea, show clearly that a very substantial loss is caused by emigration from the fishing grounds as the shoals disperse. This plays a large part in determining the duration of the fisheries, and the year-class structure of the catches.

The fate of these emigrant whiting constitutes the most important difference between the County Down and Clyde populations. In the latter group the seasonal loss of 89% also represents the annual loss; hence the fishery is almost wholly dependent upon the recruit year-class in the following year. In the County Down population, by contrast, although the seasonal loss is comparable to that of the Clyde whiting, there is a subsequent recruitment of each age group in the following season which reduces the net annual loss to 70%, with the consequence that catches contain a greater proportion of mature fish than are found in catches from the Clyde fishery.

The origin of the II+ group whiting recruiting to the County Down fishery for a second season is not clear. The data for the Irish Sea population indicate that they represent a portion of a more widely and more uniformly distributed population of older whiting. Scottish tag returns show that some of the Clyde whiting may also recruit to this area. In both regions, with the dispersion of the winter fisheries it is evident that the whiting follow a wider distribution, and separate stocks of adult whiting cannot be reliably distinguished. There is some mixing of fish between the grounds west of Scotland and within the Irish Sea, but the populations are not homogeneous and interchange must therefore be limited.

This is supported by results from an analysis of the protozoan gall-bladder parasites in whiting taken in these areas (Kabata, pers. com.). Two principal genera have been identified, *Ceratomyxa* which predominates north of latitude 55°N, and *Myxidium* which is found

south of this line in the Irish Sea. So far as is known these two organisms are mutually tolerant and generate persistent infection. With no other environmental barrier to their dispersion, this suggests that there can be only a very small exchange of whiting between the Irish Sea and the Scottish west coast grounds. The Clyde population is not characterized by either of these parasites.

The conclusion that the juvenile whiting from the County Down fishery and from the Clyde fishery subsequently recruit to more widely distributed stocks of adult fish implies that these seasonal fisheries may influence the yield of whiting in adjacent areas. This is undoubtedly true, but it does not necessarily follow that the overall yield of whiting in the area would be increased by some protective legislation for the young whiting: the distribution of the catch between nations could be changed but, other than in these seasonal fisheries, the fishing rate may not be sufficiently intensive to maintain the total catch if the juvenile fisheries were protected. These aspects of the Irish Sea fisheries are discussed in detail elsewhere (Garrod, Gambell and Hillis, 1963).

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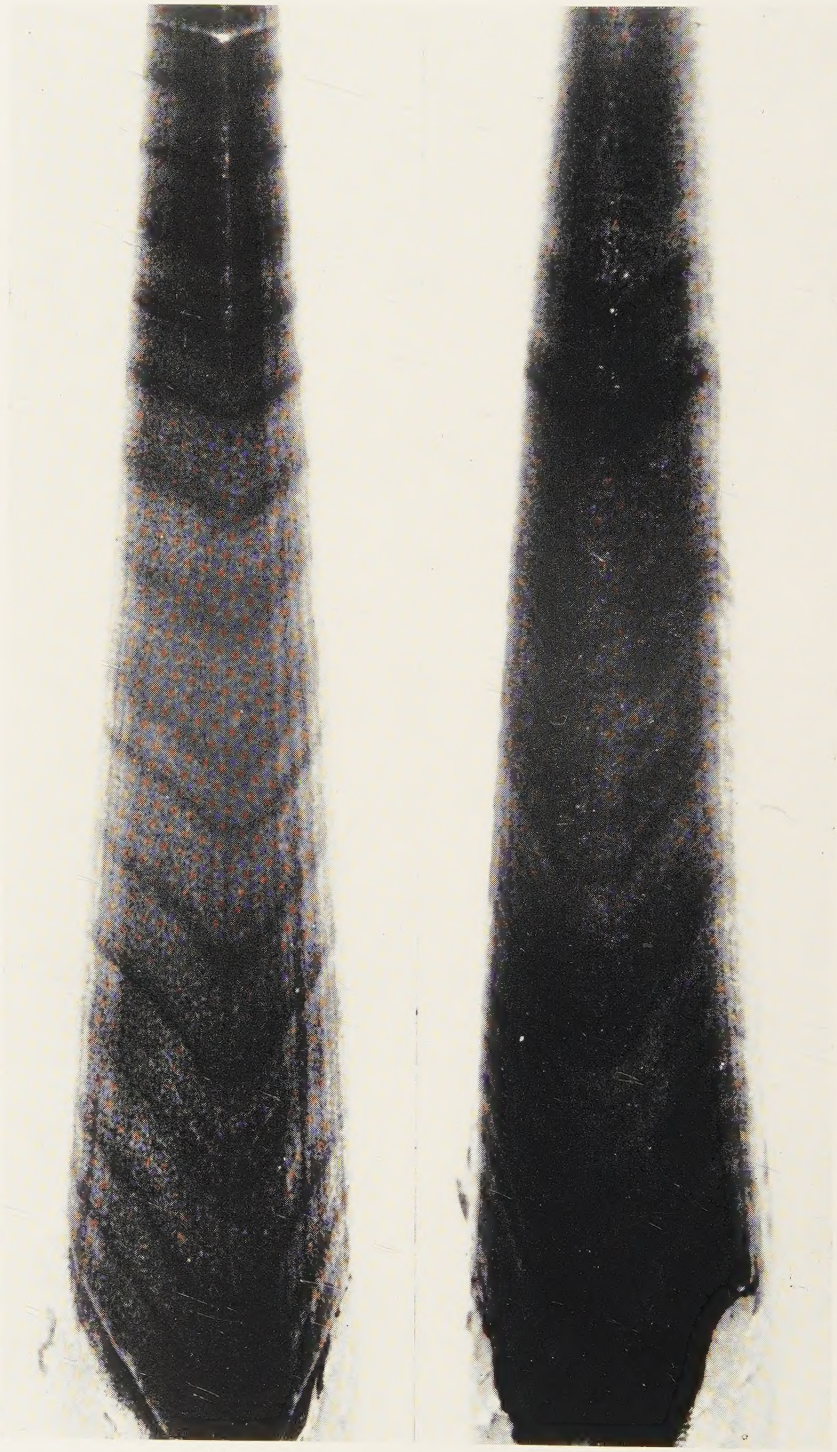

(*a*) (*b*)

Plate 1. Spurdog spines showing (*a*) *regular marks* (*b*) *irregular, secondary marks*